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COMPARISON OF THE HOURLY EVAPORATION RATE OF ATMOMETERS AND FREE WATER SURFACES WITH THE TRANSPIRATION RATE OF MEDICAGO SATIVA

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INTRODUCTION

The rate of evaporation from a free water surface or from a moist porous surface is usually considered the best single-valued expression of the intensity of the weather factors influencing transpiration. Such a relationship is, however, subject to the uncertainty arising from the marked differences in the energy-absorbing and energy-dissipating properties of the transpiring and evaporating surfaces. It is evident that the transpiring and evaporating surfaces must be in agreement in this respect if the departure of transpiration from evaporation during the day is to be taken as evidence of a change in the transpiration coefficient, resulting from stomatal control or other reversible changes within the plant body.

Fluctuations in transpiration from day to day appear to be reflected with approximately the same degree of fidelity by a number of widely different forms of evaporating surfaces, provided precautions are taken to maintain the uniformity of these surfaces throughout the period of observation. When the hourly transpiration rate is under consideration, however, the individuality of the evaporating surface to which the transpiration is referred can not be ignored. It is this phase of the question that forms the subject of the present paper.

APPARATUS AND METHODS

ATMOMETERS.—Four types of porous-cup atmometers as designed by Livingston (1915), including white cylinders, brown cylinders, white spheres, and white Bellani plates, were employed in the measurements (Pl. 4).

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Each type was represented by four atmometers[1] which were weighed independently at two-hour intervals throughout the day. The atmometers were mounted on 500-c. c. bottles closed with rubber stoppers containing a small air vent, and were freely exposed in racks about 1 meter above the ground. Distilled water was employed in all the measurements. All the atmometers used were new, and each cup was inverted and flushed with water for several hours before it was set up. The cups were set up for 36 hours before the detailed measurements were begun.

EVAPORATION TANKS.—Two evaporation tanks of widely different types were also employed in the measurements, one containing a layer of water approximately 1 cm. in depth, while the depth of the water in the other was about 50 cm.

The shallow tank, which was 91 cm. in diameter and 2.5 cm. high, was supported on a wooden disk 4 cm. in thickness and mounted about 1 meter above the ground on an automatic scale. The tank was blackened inside. The depth of water was automatically maintained at about 1 cm. by means of a Mariotte apparatus mounted on the scale platform[2] (Pl. 5). The automatic scale was sufficiently sensitive to record the loss of a layer of water 10 μ (0.01 mm.) in thickness.

The deep evaporation tank, which was 192 cm. in diameter and 60 cm. in depth, was sunk in the ground to within 10 cm. of the top. This tank was equipped with a continuously recording gauge of the float type reading to 0.1 mm.

FILTER-PAPER EVAPORIMETER.—An evaporimeter of special design, in which the evaporating surface was a saturated filter paper (12.5 cm. in diameter) was also employed in the measurements (Pl. 6). The filter paper was supported on a light flat brass disk, with a rim 1 mm. in height. The paper was kept saturated by means of a Mariotte apparatus connected with a tubulure on the lower side of the disk. This arrangement avoids the drying out of the filter paper, which is sometimes encountered in the Piche evaporimeter, due to the failure of the instrument to feed properly. The evaporation was determined by weighing the whole apparatus at two-hour intervals.

[1] The identification numbers and the coefficients of the atmometers used in the comparisons were as follows:

	No.	Coefficient.		No.	Coefficient.
White cylinders	5-36	0.77	White spheres	16-16	0.94
Do	5-37	.77	Do	16-77	.94
Do	5-57	.77	Do	16-105	.94
Do	5-142	.77	Do	16-146	.94
Brown cylinders	4-17	.74	White Bellani plates	D-137	....
Do	4-25	.74	Do	D-175	....
Do	4-41	.76	Do	D-205	....
Do	4-59	.74	Do	D-206	....

[2] This equipment is the same as that used by the writers in connection with earlier transpiration measurements (Briggs and Shantz, 1915, 1916).

TRANSPIRATION MEASUREMENTS.—The transpiration measurements were made on automatic scales of the type previously described (Briggs and Shantz, 1915). Grimm alfalfa (*Medicago sativa* L.) was employed in the measurements. The plants were growing in the large sealed pots used in the writers' water-requirement measurements, and had been carried over from the preceding year. The plants were fully exposed to the sun and were coming into bloom during the measurements, the second cutting of the season being made at the close of the experiments. The green weights of the crops and the total plant surface [1] were as follows:

Pot No.	Green weight.	Total plant surface.
	Gm.	*Sq. cm.*
301	258	15,700
303	287	17,400

SUBSIDIARY MEASUREMENTS.—In addition to the above measurements, the solar-radiation intensity, air temperature, wet-bulb depression, and wind velocity were recorded simultaneously by means of automatic instruments which have already been described (Briggs and Shantz, 1916).

REDUCTION OF DATA.—The data for the white cylinder, brown cylinder, and white-sphere atmometers have been corrected by means of the coefficients supplied with the instruments. No corrective factor has been applied to the Bellani plates. The data for the filter-paper evaporimeter have been reduced to an area of 100 sq. cm. and the data for shallow evaporation tank to an area of 1 square meter.

EXPERIMENTAL RESULTS

The measurements were made at Akron, Colo., in July, 1916, during a period of hot, dry weather. The data representing the hourly evaporation rate from the various surfaces, the transpiration rate, and the weather conditions are given in Table I. Each atmometer determination is the mean of four independent measurements. The transpiration is represented by the mean of two pots measured independently. The data are presented graphically in figure 1.

The hourly transpiration is plotted at the top of the figure, followed by the evaporation from the different types of atmometers and from the free water surfaces. It will be noted that the different atmometers, although varying widely in form (Pl. 4), give graphs which are similar in their characteristics. This is brought out more clearly in figure 2, in which the ratio of the transpiration rate to the evaporation rate for each of the various types of atmometers is plotted hour by hour.

[1] The determinations of plant surface are based upon the measurement of the green weight and total surface of a representative plant.

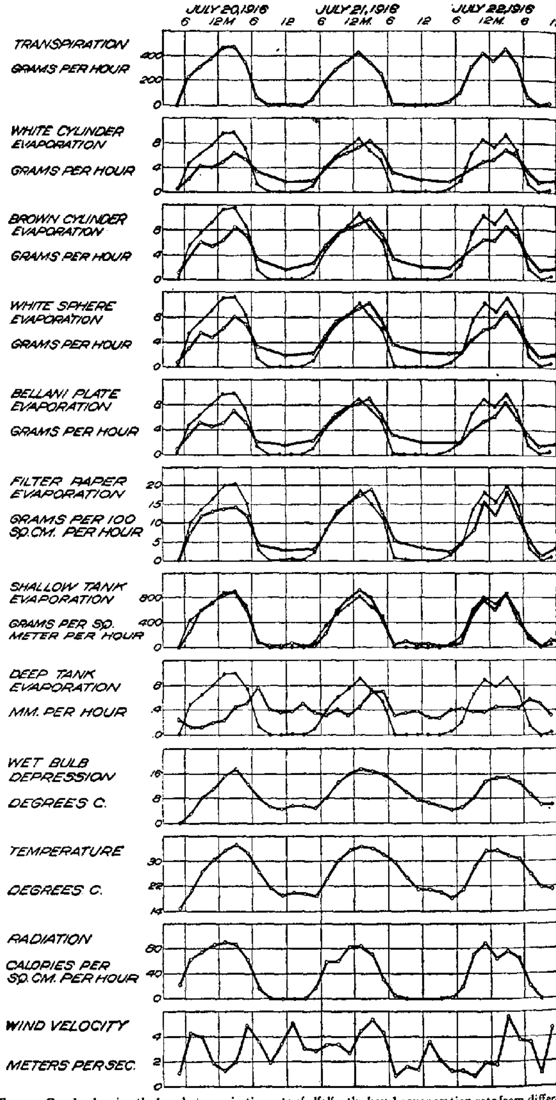

FIG. 1.—Graphs showing the hourly transpiration rate of alfalfa, the hourly evaporation rate from different surfaces, and the weather conditions during a three-day period at Akron, Colo. The heavy lines (with points marked by circles) represent the observed data. The light lines (with points marked by dots)

TABLE I.—*Hourly evaporation rate from atmometers and free water surfaces, the hourly transpiration of Medicago sativa, and the hourly intensity of weather factors*

Item.	A. M.						P. M.						Average, 8 p. m. to 4 a. m.
	12 to 2	2 to 4	4 to 6	6 to 8	8 to 10	10 to 12	12 to 2	2 to 4	4 to 6	6 to 8	8 to 10	10 to 12	
July 20, 1916.													
Transpiration of alfalfa.....gm. per hour	....	....	10	230	310	380	465	475	350	65	5	5	6
Evaporation:													
White cylinder.....do	....	....	.5	2.2	4.3	4.0	4.9	6.4	5.4	3.4	....	....	1.7
Brown cylinder.....do	....	....	1.1	3.7	6.1	5.4	6.4	8.5	7.1	3.4	....	....	1.7
White sphere.....do	....	....	.7	3.1	5.5	4.8	6.2	8.1	7.0	3.2	....	....	1.9
Bellani plate.....do	....	....	.8	3.1	5.2	4.5	5.1	7.0	5.2	2.1	....	....	1.5
Filter paper, gm. per 100 sq. cm. per hour	....	....	.0	7.0	11.5	12.7	13.5	14.2	11.8	4.1	....	....	2.7
Shallow tank, gm. per sq. meter per hour	....	....	....	260	600	725	845	900	600	95	40	40	50
Deep tank.....mm. per hour	....	....	.25	.13	.13	.19	.24	.45	.51	.76	.42	.38	....
Wet-bulb depression.....°C	....	....	.0	3.3	8.3	11.1	15.6	17.5	12.8	8.3	5.3	4.7	....
Radiation, calories per sq. cm. per hour	0	0	22	63	75	85	90	87	63	18	0	0	....
Temperature.....°C	....	....	15.0	20.6	26.7	30.5	33.6	35.3	32.8	26.7	21.4	19.2	....
Wind velocity.....meters per second	....	....	1.1	4.3	4.0	1.9	1.3	2.0	4.9	3.6	1.9	3.4	....
July 21, 1916.													
Transpiration of alfalfa.....gm. per hour	10	5	50	190	290	355	430	345	260	10	5	0	3
Evaporation:													
White cylinder.....do	....	....	1.9	4.0	5.6	6.4	7.3	8.3	6.9	3.1	....	....	2.0
Brown cylinder.....do	....	....	2.8	5.5	7.2	8.3	8.9	9.7	7.3	3.3	....	....	2.1
White sphere.....do	....	....	2.3	5.0	7.3	8.3	9.3	10.3	7.8	3.6	....	....	2.4
Bellani plate.....do	....	....	2.3	4.4	6.3	7.5	8.0	8.9	6.4	3.1	....	....	2.0
Filter paper, gm. per 100 sq. cm. per hour	....	....	3.0	8.2	12.9	15.1	17.2	18.8	12.7	5.3	....	....	3.2
Shallow tank, gm. per sq. meter per hour	75	40	40	230	590	780	920	800	435	55	105	50	65
Deep tank.....mm. per hour	.38	.51	.36	.32	.41	.33	.45	.70	.70	.32	.36	.38	....
Wet-bulb depression.....°C	5.8	5.8	5.0	8.3	13.6	16.1	17.5	16.9	15.8	13.3	10.0	7.5	....
Radiation, calories per sq. cm. per hour	0	0	18	59	61	83	84	72	31	5	0	0	....
Temperature.....°C	20.0	19.7	18.9	24.5	30.3	33.6	34.7	34.2	32.0	29.7	24.5	21.1	....
Wind velocity.....meters per second	5.1	3.[illegible]	2.9	3.4	3.4	2.7	4.5	5.4	4.3	.9	1.6	1.4	....
July 22, 1916.													
Transpiration of alfalfa.....gm. per hour	5	0	30	100	315	420	365	455	335	70	0	25	5
Evaporation:													
White cylinder.....do	....	....	1.7	1.8	3.3	4.9	5.3	6.7	5.8	3.3	1.6	....	2.1
Brown cylinder.....do	....	....	1.9	2.3	5.1	6.3	6.3	8.5	7.0	3.6	1.5	....	2.0
White sphere.....do	....	....	2.2	2.3	4.3	5.9	6.5	8.8	6.6	3.7	1.7	....	2.2
Bellani plate.....do	....	....	1.0	1.9	3.9	5.2	5.9	8.1	5.6	3.1	1.2	....	1.7
Filter paper, gm. per 100 sq. cm. per hour	....	....	2.1	4.9	7.8	15.2	11.9	18.0	11.5	5.3	1.2	....	3.6
Shallow tank, gm. per sq. meter per hour	75	30	30	75	535	760	600	865	430	185	15	115	60
Deep tank.....mm. per hour	.29	.28	.39	.42	.38	.38	.45	.45	.45	.57	.51	.32	....
Wet-bulb depression.....°C	6.7	5.6	4.4	5.3	8.3	13.6	14.7	14.7	13.3	9.4	6.1	6.1	....
Radiation, calories per sq. cm. per hour	0	0	2	20	71	89	65	77	66	21	0	0	....
Temperature.....°C	21.1	20.0	18.3	21.1	28.1	33.3	33.3	31.7	30.8	25.8	21.7	21.1	....
Wind velocity.....meters per second	3.6	2.1	1.3	1.3	.9	2.0	1.8	5.6	3.8	3.6	1.1	4.7	....

The transpiration graph has also been superimposed on each of the evaporation graphs in figure 1, choosing the scale of ordinates in each instance so that the total area under the transpiration graph for the three days is equal to the area under the evaporation graph. This affords a graphical comparison of the fidelity with which the transpiration is reflected in the hourly evaporation rate from the different instruments.

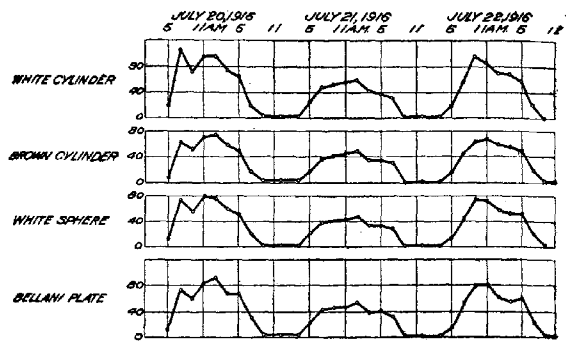

FIG. 2.—Ratio of the transpiration rate to the evaporation rate for each of the various types of porous-cup atmometers, plotted hour by hour.

MEAN HOURLY DEPARTURE OF EVAPORATION AND TRANSPIRATION

A quantitative expression of the relative value of the several instruments in predicting the hourly transpiration may be obtained by determining the average departure of the evaporation graph from the transpiration graph, the mean departures being expressed in percentage of the mean hourly evaporation in each instance. The calculation has been based both on the total period covered in the measurements and on the three daylight periods from 6 a. m. to 6 p. m. These computations are presented in Table II. The error involved in predicting the transpiration rate from the evaporation measurements is indicated by the figures in the last column of the table.

TABLE II.—*Average hourly departure of evaporation rate from transpiration rate in percentage of the mean evaporation rate for various types of atmometers and for free water surfaces*

Type of atmometer.	Day periods, 6 a. m. to 6 p. m.	Total period.
	Per cent.	*Per cent.*
White cylinder	38	49
Brown cylinder	29	41
White sphere	31	43
Bellani plate	30	41
Filter-paper evaporimeter	22	31
Shallow tank	12	17
Deep tank	93	89

The deep tank gives little indication of the hourly transpiration rate, since the average departure in this case amounts to about 90 per cent of the mean evaporation rate. In other words, the evaporation from the deep tank at different hours of the day is not proportional to the transpiration of the plant.

The average hourly departure in the case of the white cylinders amounts to about 50 per cent of the mean hourly transpiration. In other words, the average error in predicting the amount of transpiration at each hour in the day from the evaporation when the ratio of daily transpiration of the plant to the daily evaporation of the atmometer is known would amount to one-half the mean hourly value of the transpiration. When the brown cylinder, Bellani plate, or white sphere is used, this error is reduced to about 40 per cent. In the case of filter-paper evaporimeter the error is reduced to about 30 per cent. The best results were obtained with the shallow, blackened tank, the error being less than 20 per cent.

Since the night values of transpiration and evaporation are low and the greater part of the evaporation and transpiration occurs during the daylight hours, the writers have also computed the mean departure of each of the different instruments on the basis of the daylight hours only. The departures, with the exception of the deep tank, are, in this case, about two-thirds of those for the total period. The evaporation rate of the shallow, blackened tank during the daylight hours again follows the transpiration graph more closely than that of any of the other instruments, the mean departure being only about two-fifths that observed in the case of the atmometers. The filter-paper evaporimeter also shows a lower mean departure than the atmometers. Of the latter instruments, the brown cylinder, white sphere, and Bellani plate are practically identical and show a departure of about 30 per cent, while the white cylinder shows a somewhat greater mean departure. The similarity of the results from the three first-named types is remarkable when the difference in form and color are considered.

The evaporation from the deep tank shows practically no correlation with the transpiration when the hourly values are considered. Attention has already been called to this discrepancy, which results from the storage of heat energy in the great mass of water during the day and its slow dissipation through evaporation during the night. The maximum in the evaporation graph from the deep tank occurs in the late afternoon or early evening.

The fact that an evaporating surface shows a low correlation with the hourly transpiration does not necessarily imply a correspondingly low correlation on a daily basis. This is demonstrated in the case of the deep tank, which showed in 1914 (a dry year) a correlation with transpiration of 0.63 ± 0.01 (Briggs and Shantz, 1916a), while the correlation of the shallow tank for the same period was 0.72 ± 0.01. The evaporation from the deep tank probably represents approximately the distribution of the

loss of water from a large body of water, heat energy being stored in both systems during the day. The transpiration graph of alfalfa may be assumed to represent approximately the distribution of the hourly loss of water from any actively growing vegetative cover. The hourly loss from large bodies of water thus appears to be more nearly uniform throughout the 24-hour period, while the loss from land areas covered with vegetation is confined almost wholly to the daylight hours and largely to the midday period.

INFLUENCE OF WIND VELOCITY AND SOLAR-RADIATION INTENSITY ON EVAPORATION

It is of interest to consider the departure of the various evaporation graphs from the transpiration graph in relation to the intensity of the several climatic factors. It will be noted that all the atmometer graphs showed a relatively low evaporation from 10 a. m. to 4 p. m. on July 20 compared with either the transpiration or the shallow-tank evaporation. The explanation of this may be found in the wind velocity, which is relatively low during this period, being less than 2 meters per second (4 miles per hour). The relatively high evaporation from the atmometers from 2 to 6 p. m. on the following day (July 21) is also explainable on the basis of the high wind velocity during this period. The maximum evaporation from the atmometers on the third day also coincides with the period of maximum wind velocity. It is evident, therefore, that the evaporation from the atmometers is affected to a much greater degree by variations in wind velocity than either the transpiration or the evaporation from the shallow tank.

On the other hand, the atmometers are less sensitive to changes in solar radiation than either the plant or the shallow tank, as is shown by the afternoon readings on July 22. Both the transpiration graph and the shallow-tank evaporation graph show maxima at 11 a. m. and 3 p. m. on this date, due to a temporarily clouded sky from 12 noon to 2 p. m. The radiation on July 22 was also deficient from 7.45 a. m. to 11 a. m. due to the passing of cumulus clouds. This reduced the transpiration and shallow-tank evaporation and brought the transpiration graph more nearly into conformity with the atmometer graphs during this period.

ATMOMETER CALIBRATION AND OBSERVATION ERRORS

Since four instruments of each type were used in the atmometer readings, it is possible from the results to determine the calibration error and the probable error of a single observation for each individual atmometer. To each determination was applied the calibration correction which accompanied the instrument (see footnote, p. 278). The ratio of the individual observation of each instrument to the mean

of the four instruments was then taken. Since each of the instruments had been calibrated, the departure of the mean of this series of ratios from unity represents the error in the calibration coefficient. These departures, which are given in the third column of Table III, show errors ranging from +4 to −2 per cent for the white spheres, from +3 to −4 per cent for white cylinders, and from +2 to −2 per cent for the brown cylinders.

TABLE III.—*Calibration error and probable error of single observation for individual atmometers*

Atmometer.	Ratio to mean.	Observed error in coefficient.	Probable error of single observation.
White cylinder:		*Per cent.*	*Per cent.*
5–36	1.02	+2	±3.7
5–37	.96	−4	±1.7
5–57	1.03	+3	±1.9
5–142	.98	−2	±2.7
White sphere:			
16–16	.98	−2	±2.3
16–77	.98	−2	±1.7
16–105	1.00	0	±1.6
16–146	1.04	+4	±3.2
Brown cylinder:			
4–17	1.01	+1	±2.6
4–25	.98	−2	±1.5
4–41	1.02	+2	±2.5
4–59	.98	−2	±2.6
Bellani plates:			
D–137	.94	....	±3.0
D–175	.96	....	±1.8
D–205	1.03	....	±2.6
D–206	1.07	....	±3.2

The probable error of a single observation of each of the instruments has also been computed for each instrument. The results are given in the last column of the table. These errors, which do not include the errors in the coefficient, amount to from 2 to 4 per cent. It is possible from these data to obtain an expression of the degree of reliance to be placed upon individual observations. Determinations with a single atmometer at 2-hour intervals during the day thus appear to be subject to a probable error of about 5 per cent,[1] if the weighings are accurate to 0.1 gm. This probable error refers only to calibration uncertainties and to so-called "accidental" errors, as exemplified by the variation of the individuals in a group of atmometers of the same type. It does not include, for example, errors arising from the possible failure of the whole group of atmometers to respond freely to changes in their environment.

[1] Based upon the square root of the sum of the squares of the mean values of the calibration error and of the observation errors, taken without regard to sign.

RATIO OF TRANSPIRATION TO EVAPORATION

The ratio of the transpiration rate to the evaporation rate from an atmometer should give a straight line when plotted hour by hour if the two systems respond alike to changes in environment. The experimental graph is, however, periodic in form, exhibiting a marked minimum during the night hours.

Fluctuations in the hourly transpiration-evaporation ratio as represented in such a graph have been interpreted (Livingston, 1906, 1913; Livingston and Hawkins, 1915; Edith Shreve, 1914 and 1915; Forrest Shreve, 1914; Burns, 1915) as representing departures in the transpiration rate of the plant from that which would prevail if the plant responded freely to its environment. This point of view implies the assumption that an atmometer responds perfectly to its environment; in other words, that the evaporation rate from the atmometer affords a perfect summation of the environmental conditions determining evaporation from a plant surface. A departure in transpiration from that indicated by this summation would then, according to this viewpoint, be taken as evidence of a change in the transpiration coefficient resulting from stomatal control or from other reversible changes within the plant body.

The correctness of the assumption relative to the perfect response of the porous atmometers must be questioned when the hourly evaporation rate from the atmometer is compared with that from the shallow tank. During the night, for example, the evaporation from the atmometers is relatively much higher than from the free water surface. If the atmometer is accepted as responding freely to its environment, then the free water surface, even under conditions of low evaporation, can not be considered as a free evaporating system.

The same question as to the free response of the porous atmometers to their environment arises when the relative transpiring power, as expressed by the transpiration-evaporation ratio, is compared with the "index of transpiring power" as measured by the cobalt-paper method. Livingston (1913, p. 24) has in fact found in comparing the hourly graphs obtained by the two methods that the—

> relative transpiration ratio as determined either by the brown or white atmometer presents a much flatter graph than that indicated by the hygrometer index of transpiring power.

It is evident, therefore, that one of these instruments must fail to respond freely to the intensity of the environment.

The ratio of the transpiration rate of *Medicago sativa* to the evaporation rate of each of the different types of atmometers is presented graphically in figure 2. The graphs are markedly similar in form when the wide differences in the porous atmometers are considered. The changes from hour to hour in any one graph are, with few exceptions, reflected in all the others, and such differences as exist are, in most cases, comparable

with the probable error. In other words, the relative evaporation rate through a 24-hour period is practically the same whether the porous evaporating surface is in the form of a closed vertical cylinder, a sphere, or a flat horizontal plate. The brown cylinder, owing to its higher evaporation rate during the daylight hours, reduces the ordinates of the ratio graph; but otherwise this graph is also similar in form to those obtained with the white porous surfaces. When the transpiration of the plant is referred to the evaporation from a free water surface in a shallow blackened tank, a different form of transpiration-evaporation graph is obtained, which shows less daily fluctuation than when the transpiration is referred to the porous atmometers.

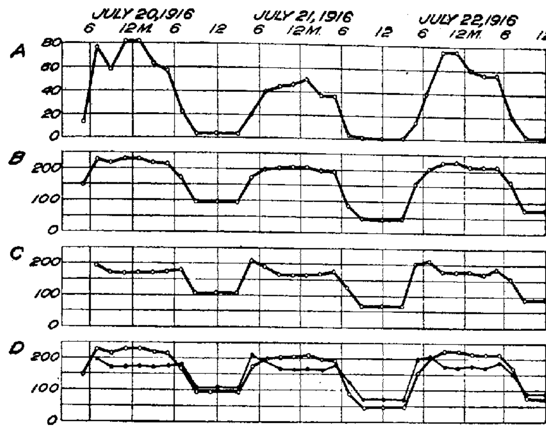

FIG. 3.—Graphs showing the transpiration-evaporation ratio: *A*, The ratio of the hourly transpiration to the hourly mean evaporation from the atmometers. *B*, Graph A with ordinates plotted logarithmically. *C*, The ratio of the hourly transpiration to the hourly evaporation from the shallow tank, with ordinates plotted logarithmically. *D*, Graphs B (heavy line) and C (light line) superimposed.

These two types of graphs are compared in figure 3. The first graph (A) of the figure represents the ratio of the transpiration rate to the mean evaporation rate of the four types of atmometers (16 instruments in all). This is the form in which the transpiration-evaporation graph is usually presented. It is however preferable, in the opinion of the writers, to plot the logarithms of the ratios, as this avoids the distortion of the graph, especially when ratios on both sides of unity are being considered. In the second graph (B) in figure 3, the transpiration-evaporation ratio, as given in the first graph, is plotted logarithmically. The third graph (C) represents the transpiration-evaporation ratio when the evaporation from the shallow tank is used as a basis of reference, and is also plotted logarithmically. At the bottom of figure 3 the last two graphs (B

and C) are superimposed. It will be noted that the fluctuation in the ratio throughout the 24-hour period, as well as the mean hourly departure, is decidedly less when the transpiration is referred to the evaporation from the shallow, blackened tank. In other words, the transpiration of *Medicago sativa* follows the evaporation from the shallow, blackened tank more closely than that from the porous atmometers.

It is evident, however, that an evaporating system has not yet been secured that responds to its environment in the same way as the plant. Both the atmometer and the tank depart widely from the plant during the night under the conditions prevailing in the Great Plains. Reference to the logarithmic graphs will show that the transpiration-evaporation ratio when referred to the evaporation from the shallow, blackened tank is practically constant from 8 a. m. to 4 p. m., the period during which the plants are transpiring most rapidly. In *Medicago sativa*, at least, there is no evidence of a change in the transpiration coefficient during this period. The higher ratio obtained in the early morning and late afternoon hours is perhaps explainable by the difference in exposure of the plants and the free water surface. The isolated plants are exposed to the normal rays of the sun practically throughout the day while the tank receives only the vertical component of radiation. Where vegetation is massed under field conditions, the plants likewise are exposed for the most part only to the vertical component of radiation.

The transpiration measurements in these experiments are confined to *Medicago sativa*, and it is possible that the transpiration rate of other plants under the same conditions would have given transpiration graphs differing in form from those obtained. Earlier measurements (Briggs and Shantz, 1916, p. 638) have shown, however, that in the case of rye and amaranthus, the hourly transpiration rate is correlated with the evaporation rate from the shallow tank to a degree comparable with the corresponding correlation in the case of alfalfa. Thus, for rye and amaranthus correlations of 0.89 ± 0.03 and 0.95 ± 0.01, respectively, were obtained, while alfalfa at different periods during the same year showed a correlation of 0.89 ± 0.01 and 0.93 ± 0.01. An equally good correspondence would therefore be expected, at least in the case of amaranthus, between the hourly transpiration rate and the hourly evaporation rate from the shallow tank.

The writers are not, however, urging the merits of the shallow, blackened tank as a means of determining changes in the transpiration coefficient of a plant during the day. The point which it is desired to emphasize is that departures between the hourly transpiration rate and the hourly evaporation rate from any physical system can not be attributed to changes in the transpiration coefficient without first having determined that under less intensive conditions the two systems give graphs which are in accord.

THE ATMOMETER AS A MEANS OF MEASURING SOLAR-RADIATION INTENSITY

The simultaneous measurement in the above determinations of the intensity of solar radiation and the evaporation rate from brown and white atmometers affords an opportunity of testing the atmometer as a means of measuring radiation intensity. The radio-atmometer, in which the evaporating surface is darkened so as to absorb as much of the incident radiation as possible, was developed by Livingston (1915, p. 147) primarily for—

> measuring the effectiveness of solar radiation as an accelerator of evaporation. It has not been shown to be available for measuring solar radiation as a whole, though its readings no doubt approximate such measurements to a greater or smaller degree.

However, if the increase in evaporation of the radio-atmometer over the white atmometer affords a correct measure of the effect of the intensity of "solar radiation as an accelerator of evaporation" independently of

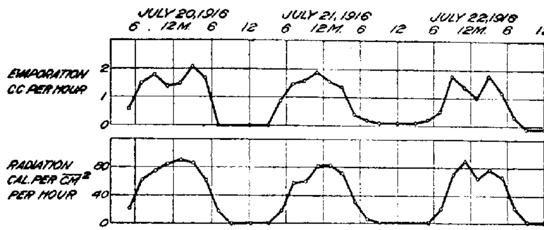

FIG. 4.—A comparison of the hourly radiation with the hourly differences in the evaporation rate from a brown cylindrical radio-atmometer and a white atmometer of the same form.

any peculiarities of the instrument itself, then, conversely, the excess evaporation of the radio-atmometer over the corresponding white type should afford a measure of the intensity of the incident radiation. It is from this latter standpoint that the data are presented. The radio-atmometers employed were of the brown cylindrical type[1] mounted with the cylinders vertical, and in this position do not present a uniform surface area to the march of the sun during the day, as Livingston has already pointed out. Furthermore, the radio-atmometers did not absorb all the incident radiation, the surfaces being brown in color instead of dead black; but, since the coefficient of absorption of a surface does not vary with the amount of energy received, this factor is not of importance in this connection.

The hourly excess of the evaporation from the radio-atmometer over that of the corresponding white cylinders is plotted in figure 4 for the

[1] The new spherical radio-atmometers recently developed by Livingston were not available at the time these measurements were made.

three days during which detailed measurements were made. This hourly excess represents the difference in the hourly values for the brown and white cylinders, as summarized in Table I, which in each instance are based upon the mean of four radio-atmometer observations and the mean of four white-cylinder observations. For comparison, there is also plotted in figure 4 the radiation received on a surface normal to the sun's rays, as measured by a differential telethermograph calibrated by means of an Abbot pyrheliometer. The integrated radiation—that is, the area inclosed by the graph—for each of the three days investigated, expressed as a percentage of the mean of the three, is as follows: 114, 94, 93. The corresponding excess evaporation of the cylindrical radio-atmometers over the white cylinders for the corresponding three days, expressed also as a percentage of the mean, is 113, 101, 85.

It is of interest to consider in this connection the energy represented by the radiation falling on the cylinder compared with the energy dissipated in the water evaporated. If we consider the mean of all the 11 a. m. to 1 p. m. values for the three days, the mean incident radiation on the radio-atmometer computed from a formula developed by the writers (Briggs and Shantz, 1916a, p. 186) is approximately 1,100 gram-calories per hour, while the average hourly differential evaporation at 11 a. m. and 1 p. m is 1.5 gms., corresponding to the dissipation of 800 gram-calories per hour. The energy dissipated in the water evaporated thus represents about three-fourths of the total incident energy. The brown cylinder is not a perfect absorbing surface, so that the incident energy would be expected to exceed that dissipated in evaporation, as was found to be the case. It may be possible with the improved spherical atmometers to develop a definite relationship between the incident radiation and the excess evaporation from the black surface, in which event black and white spherical atmometers, when employed together, may be used to measure the intensity of radiation. Black and white Bellani plates may perhaps be used also to measure the vertical component of radiation.

SUMMARY

This paper deals with a comparison of the hourly transpiration rate of alfalfa with the hourly evaporation rates from various types of porous-cup atmometers, a filter-paper evaporimeter, a blackened, shallow tank, and a deep tank.

The comparison between the transpiration rate and the evaporation rate was made by superimposing the hourly transpiration graph on each of the hourly evaporation graphs, choosing the scale of ordinates of the transpiration graph so that the total area under the transpiration graph was equal to the total area under the evaporation graph. The average hourly departure of each of the evaporation graphs from the superimposed transpiration graph expressed in percentage of the mean transpiration

for the day was then determined. For the shallow tank the mean hourly departure for the 24-hour period was 17 per cent; for the filter-paper evaporimeter 31 per cent; for the brown cylinder, white sphere, and Bellani plate about 40 per cent; for the white cylinder about 50 per cent; and for the deep tank about 90 per cent of the mean hourly transpiration. The corresponding departures for the daylight hours from 6 a. m. to 6 p. m. were as follows: For the shallow tank, 12 per cent; filter-paper evaporimeter, 22 per cent; brown cylinder, white sphere, and Bellani plate atmometers, about 30 per cent; white cylinder atmometer, 38 per cent; and the deep tank, 93 per cent.

Since the hourly evaporation graphs of the various evaporation systems employed differ widely in form, it does not seem justifiable to attribute the discrepancy between the observed hourly transpiration and that calculated from the evaporation rate of any particular system to a change in the transpiration coefficient of the plant during the day, unless it can be shown that under less extreme conditions the transpiration rate is in accord with the evaporation rate. The plant may not be responding freely to its environment, but a departure in its relative transpiration rate from the evaporation rate of an arbitrarily chosen physical system does not necessarily establish this fact. A close correspondence does not appear to exist between the hourly transpiration rate of normal alfalfa plants and the hourly evaporation rate of any of the systems employed in this investigation. The best agreement in this instance was obtained with the shallow, blackened evaporation tank.

The departure of the hourly evaporation rate of the porous-cup atmometer from the hourly transpiration rate of alfalfa is due largely (1) to the marked increase in the evaporation over transpiration during the night hours; (2) to the marked response of the atmometers to changes in wind velocity, which were not accompanied by corresponding changes in the transpiration rate; and (3) to the lack of a proportionate response on the part of the atmometers to changes in solar radiation.

It should be emphasized in this connection that the failure of an evaporating surface to show a high correlation with the hourly transpiration rate does not necessarily imply a correspondingly low correlation on the daily basis. This is strikingly illustrated by the hourly evaporation rate from the deep tank, which, in these experiments, shows practically no correlation with the hourly transpiration rate, but which on a daily basis was found in 1914 to be correlated with the daily transpiration rate to the extent of 0.63 ± 0.01.

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PLATE 4

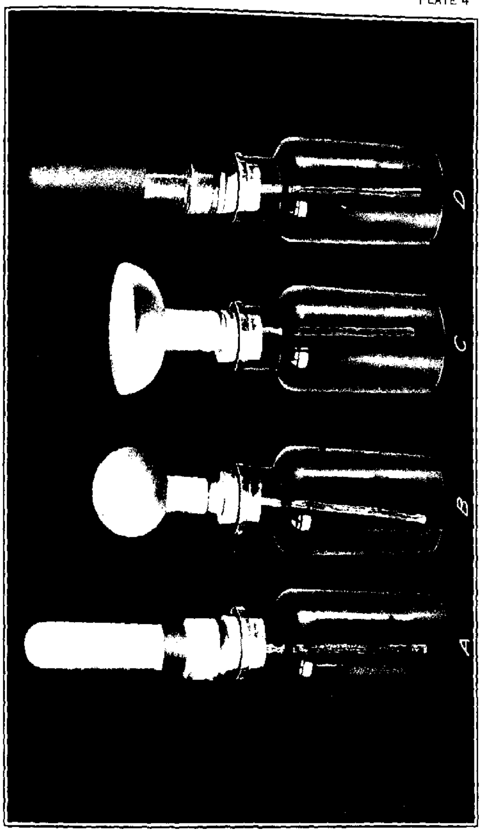
Types of porous-cup atmometers used in evaporation measurements:

A.—White cylinder.

B.—White sphere.

C.—White Bellani plate.

D.—Brown cylinder.


A
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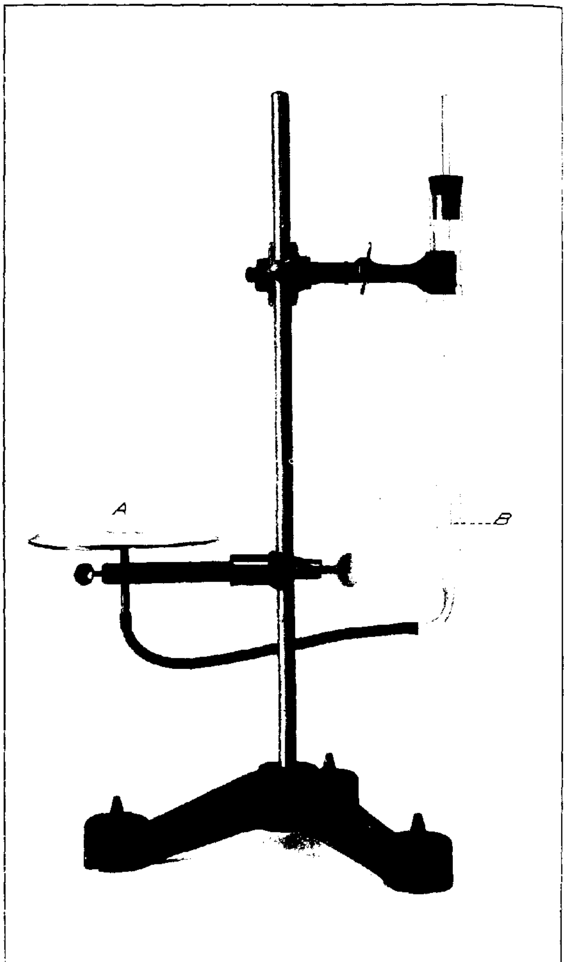

A
B

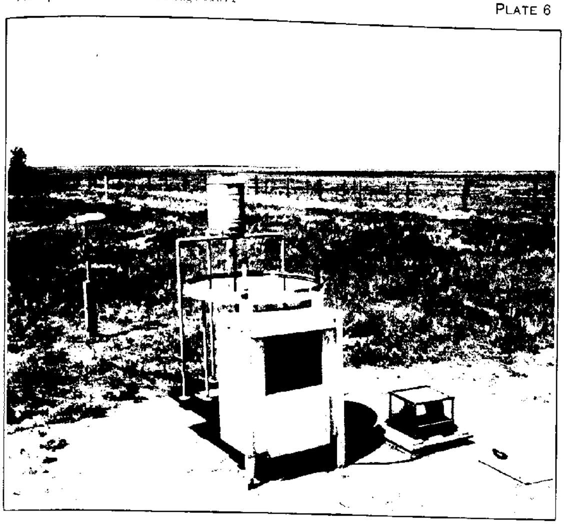
PLATE 5

Special filter-paper evaporimeter used by the writers, equipped with Mariotte control (*a*) for the purpose of maintaining a constant water level in the filter-paper container (*b*).

PLATE 6

A.—Shallow, blackened evaporation tank mounted on automatic balance. The reservoir is shown above in the back. The tank has an area of 6,540 sq. cm., and the water is maintained at a depth of approximately 1 cm.

B.—Deep evaporation tank as used at Akron, Colo. This tank is 6 feet in diameter and 2 feet in depth, and is buried in the ground to within 4 inches of the top. The water level is kept at 4 ± 1 inches from the top of the tank. The well of the recording gauge (not shown in the figure) is connected with the tank by a buried pipe. The well for the micrometer gauge may be seen (covered) on the right side of the tank.



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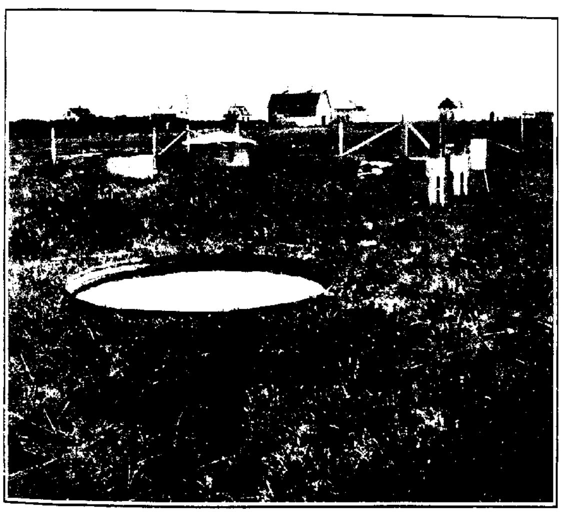

B

INFLUENCE OF CROP, SEASON, AND WATER ON THE BACTERIAL ACTIVITIES OF THE SOIL

By J. E. GREAVES, ROBERT STEWART, and C. T. HIRST, *of the Departments of Bacteriology and Chemistry, Utah Agricultural Experiment Station*

INTRODUCTION

It is of the utmost importance that the quality and quantity of plant food rendered available during the season nicely balance that required by the growing plant, for then we have maximum yield with minimum loss of soil fertility. Most of the changes which take place in the soil constituents are wrought by microorganisms, which bring about the transformation through which nitrogen passes in the soil—that is to say, the transformation from its inert form in the atmosphere to a form available to the growing plant. Furthermore, they play an essential part in the cycles through which hydrogen, sulphur, and carbon pass. Bacteria bring about the mineralization of calcium, iron, phosphorus, and many other inorganic constituents of the plant and animal residues in the soil. Moreover, many of these substances are changed from the insoluble to the soluble form and thus are made available to the growing plant by bacterial activity. At times bacteria have an opposite effect and render many of these substances insoluble, thus preventing in a degree their loss to the growing plant. Or at times they may even compete with the higher plant for the limited supply of nutrient in the soil.

The speed with which these transformations take place within a soil is governed, amongst other factors, by the season of the year, the crop growing upon the soil, and the water which that soil receives. These investigations were undertaken, therefore, with the hope of throwing definite light upon the magnitude of these influences and, furthermore, to correlate the results obtained by the various methods, one with the other, and these in turn with the crop-producing powers of the soil. For these reasons in this work a direct determination was made of the nitric-nitrogen content of the soil as soon as it was taken from the field while other portions of the same samples were used for the determination of the ammonifying and nitrifying powers of the soil. Counts were also made of the number of bacteria developing from the soil on synthetic agar.

A careful review of literature dealing with this phase of the subject has been made, and there is given below a résumé of the most important.

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HISTORICAL REVIEW

INFLUENCE OF MOISTURE

Long before the process of nitrification was known to be due to microorganisms, the underlying principles governing the speed of the reaction had been investigated nationally by France, Germany, and Sweden. Among other things, they had learned that there must be a certain proportion of water, and, in order that the maximum yield of nitrates be obtained, that this must be diminished as the soil becomes richer in nitrates. As early as 1887 Dehérain (9) found that the most active nitrification took place when the soil was allowed to become partially dry between the applications of water, and later (12) he found that there was a relationship between the speed of nitrification and the moisture content of fallow soil, the nitrification increasing with the water. Boussingault (63) taught that, when soils contain as much as 60 per cent of water, they lose in a few weeks the greater part of their nitrates. This teaching gave rise to the general belief that dentrification may take place to a great extent in soils, but recent work has amply demonstrated that it is only under extremely abnormal conditions that this becomes an important factor. For this reason literature bearing on this phase of the subject is not considered here.

Dehérain and Demoussy (14) found that the bacterial action of a soil was at its maximum when a rich soil contained 17 per cent of water, but that it decreased if the proportion of water fell to 10 per cent or rose to 25 per cent. With soils less rich in humus a somewhat higher proportion of water was necessary to retard oxidation to any marked degree.

The optimum moisture content for nitrification, according to Dehérain (13), is 25 per cent. An insufficient supply of moisture checked both nitrification and nitrogen fixation. This occurred when the water had been reduced to 16.5 per cent. This, however, would vary with the soil, for Schlœsing (50) found bacterial activity less in fine-grained soils than in lighter, coarse-grained soils. In order that nitrification be equally active in both light and heavy soils, the latter must have a higher percentage of water than the former, a difference in moisture content of soil of 1 per cent, according to Dafert and Bollinger (8), being sufficient to produce a marked change in the oxidation going on in the soil.

Fraps (16) found that the number of nitrifying organisms in a soil varies with the moisture and that their activity was periodic, rapid nitrification being preceded and followed by periods of less activity. Later he (17) found nitrification to be at its height in soil containing 55.6 per cent of its water capacity. Excessive quantities of water practically stopped nitrification and was much more injurious than too small a quantity. The water requirements, however, varied considerably with the soil.

Coleman's (7) work with a loam soil showed nitrification to be most active when the soil contained 16 per cent of water. It was greatly retarded when the water content was reduced to 10 per cent or increased to 26 per cent. Not only nitrification but ammonification is dependent upon the moisture content of the soil. However, Lipman and Brown (31) found ammonification in a loam soil increased with increased water content even up to 35 per cent of the weight of the soil; but nitrification was most active in the same soil with a moisture content of 15 per cent, was only slightly less active with 10 per cent of moisture, and was still quite marked when the soil contained only 5 per cent of moisture. However, later Lipman, Brown, and Owen (32) found ammonification to increase as the water added increased up to a certain percentage, which varied with the physical nature of the soil; but larger quantities of water reduced the ammonia recovered. Moreover, the work clearly demonstrates that the optimum moisture content for maximum ammonification is higher than it is for maximum nitrification.

Engberding (15) considered that the moisture content of a soil had a greater influence on numbers than did temperature; and the work of King and Doryland (30) clearly indicates that excessive soil moisture reduces both the number and activity of soil bacteria.

Patterson and Scott's (43) work is interesting in that they found nitrification to be inactive in sand and clay soils which still contained about three times as much moisture as in their average air-dry condition. At the lower limits of moisture less water starts nitrification in sand than in clay. At the higher limits of moisture less water stops nitrification in sand than in clay, while the optimum amount of water probably varies for each soil; it is higher for clay, yet for both soils it lies within the range of from 14 to 18 per cent. A rise above the optimum amount of water is more harmful than an equal fall below it.

The work of the Utah Experiment Station (56) demonstrated that the application of irrigation water to a soil has a distinct beneficial effect upon nitrification, being greatest where 15 inches of water were applied when the nitric nitrogen formed amounted to 28.5 pounds per acre-foot of soil. The greatest benefit per inch of water, however, was obtained where only 7.5 inches of water were applied, resulting in 3.8 pounds of nitric nitrogen per inch of water, while where 15 inches of water was applied it was 1.1 pounds of nitric nitrogen per inch of water applied, and when 25 inches of water was applied to the soil the nitric nitrogen produced was only 0.7 pound.

Münter and Robson (4) found that horn meal decomposed more rapidly in dry sandy soil than in clay or loam, while with higher moisture content there was little difference. Ammonium sulphate transformation increased with a higher water content. The best nitrate formation from horn meal occurred in sandy soils. In clay and loam it was best with a

medium water content. Sharp (52) found that the water content most favorable for ammonification was not the optimum condition for nitrification. The former was most rapid with a 25 per cent water content and was not markedly affected by 3 per cent differences. Nitrification was at its maximum when the soil contained 19 per cent of water. When it was increased to 25 per cent, the rate of nitrification was decreased 50 per cent.

McBeth and Smith (38) found a slight variation in the number and nitrifying powers of soil, depending upon the moisture content. However, Gainey (18) considers that among the factors controlling the bacterial activity of a soil the available moisture probably plays a leading part. But we (22) have reported results which indicate that the nitrous nitrogen content of a soil is independent of the irrigation water applied up to 37.5 inches a year. Results recently published from the Utah Experiment Station (21) clearly demonstrate that the influence exerted by water upon ammonifying, nitrifying, and nitrogen-fixing activities of the soil varies greatly with the organic matter in the soil and is much more marked in effect on soils recently manured than on those which have received no manure.

From the literature cited it may be seen that the number of bacteria in a soil and the ammonifying and nitrifying powers of the soil are functions of the moisture content of the soil, and that the optimum varies with the physical and possibly the chemical properties of the soil. But in all soil, to obtain the maximum count and ammonification, the moisture content should be about 6 per cent higher than to obtain maximum nitrification. While the optimum for nitrification varies with different soils, the average would seem to be between 18 and 20 per cent of moisture.

INFLUENCE OF CROP

Even as early as 1855 the work at Rothamsted (48) had demonstrated that the beneficial effects of fallowing lies in the increase brought about in the available nitrogen compounds of the soil. Dehérain and Demoussy's (14) work indicated that there is a larger production of nitrates in fallow than in cropped soils, and Pfeiffer (44) considers fallowing an extreme form of soil robbery, for he found that it promotes the activity of the soil organisms and, hence, hastens the exhaustion of the nitrogen supply. But, as it is so clearly pointed out by Warington (63), these results may not hold in a dry climate or during dry seasons; for here bare fallow may not necessitate this loss, and much is to be gained by its practice. But it must always be borne in mind that, if there be sufficient moisture, the loss may be great. For instance, Schneidewind, Meyer, and Münter (51) record a loss in fallow plots of 85.5 pounds per acre, which even exceeded the nitrogen removed by the growing plant on the cropped soil.

On the other hand, McBeth and Smith (38) claim that plots continuously cropped to alfalfa, potatoes, oats, and corn all show a higher nitrifying power than do corresponding fallow plots and that the stimulating effect of crop production on the nitrifying power of a soil is most marked in alfalfa soil. This is in keeping with the recent findings of Vel'bel (60), but is contrary to the findings of many other investigators; for Heinze (24) found fallow to increase the pectin, cellulose, and humus fermenters and also the ammonifiers, nitrifiers, and Azotobacter. Russel (48) finds that in late summer fallow land is richer in nitrates than cropped, even after allowing for the nitrogen taken up by the crop; and Heinze shows that repeated cultivation of fallow soil increases the number of organisms in the soil, while Hiltner (25) maintains that no nitrification occurs in soils where legumes are growing vigorously and fixing large quantities of nitrogen. This latter view, however, is the extreme, as is shown by much of the literature on the subject.

Vel'bel and Winkler (61) found that fallow not only increased the assimilable nitrogen but also the available phosphoric acid of the soil and that the increased yield of wheat after fallow is due to these factors. But Bychikhin and Skalski (5) point out that fall fallow is even more wasteful of soil nitrates than is summer fallow, for here the excessive rains wash the soluble nitrates from the soil as fast as formed. The cultivating of fallow further increases the nitrate content, as was shown by Richardson (47). Not only nitrification but all the bacterial activities of a soil are increased by fallow, as may be seen from the following table from the work of the senior author (20) of this paper.

TABLE I.—*Average bacterial content and activity of soil with various crops*

	Colonies.	Mgm. of NH_3 formed.	Mgm. nitric nitrogen formed.	Mgm. of N fixed.
Virgin soil	2.270	43.88	2.09	14.28
Wheat soil	4.840	52.94	4.00	6.99
Alfalfa soil	3.911	50.52	2.25	11.83
Fallow soil, potato fallow, etc	3.980	83.42	6.22	22.88

The results reported under milligrams of nitrogen fixed indicate that in an arid soil the increased nitrogen fixation in a fallow soil more than offsets the loss of nitrates, even though rapidly formed, for little, if any, would be lost in the drainage waters. These results have recently been confirmed by Reed and Williams (46). Moreover, the number of organisms in the soil and the rapidity of the bacterial activity within the same is going to vary greatly with the thoroughness and time of cultivation, as shown by Dehérain (11), Neish (42), King and Whitson (29), Chester (6), and Quiroga (45), while the number and activity of the organisms in the soil may in a degree determine the speed with which the water evaporates from a soil (57).

The work at the Rothamsted station (63) early demonstrated that the nitrates in the drainage water from the various plots varied greatly, depending upon the crop growing upon the soil, thus indicating a relationship between the available nitrogen in a soil and the crop growing upon the soil; since that time many experimenters have confirmed this conclusion. Furthermore, King and Whitson (28) found 22 per cent more nitrogen developed from soil after clover than from soil after corn, and 13 per cent more than after oats. Later work by them (29) showed that there are greater quantities of nitrates throughout the entire season in soil under corn or potatoes than in soil under clover and oats. Stewart and Greaves (54) found that different plants show a marked difference in their demands upon the nitrate content of the soil, there being a steady decrease in the concentration of the nitrate content of potato and corn lands as the season progressed, while that of fallow and alfalfa remained practically constant, the nitrate content of the latter being uniformly low throughout the season. According to Lyon and Bizzell (33), soil that had produced alfalfa for five years was higher in nitrates than soil that had grown timothy during the same period. Furthermore, the former nitrified ammonium sulphate more readily than did the latter.

Brown (3) found that the rotation of crops caused an increase in number of organisms in a soil, also greater ammonifying, nitrifying, and nitrogen-fixing powers than continuous cropping to either corn or clover. Furthermore, the crop on the soil at time of sampling was of more importance from the bacterial standpoint than the previous crop. However, the preceding crop has a marked effect upon the nitrate content of the soil, as is seen from the work of Lyon and Bizzell (35), where plots that had been planted to certain crops were kept bare of vegetation in the early part of the growing season of 1911. Nitrate determinations of the soil were made and the nitrate present showed a distinct and characteristic relationship to the nitrate content found under the several varieties of plants previously grown upon the soil. Later they (36) showed that alfalfa soil nitrified more rapidly than timothy soil, both in the soil on which the crops had been grown continuously and in that from which they had been removed and the soil kept bare for two seasons. However, one of us (20) has shown that the nitrifying powers of alfalfa soil, while slightly higher than that of virgin soil, is very low when compared with either wheat or potato and fallow soil. Furthermore, the extensive work which has already been published from the Utah Experiment Station (54) demonstrates that there is a very pronounced relationship between the crop growing upon a soil and its nitrate content. However, in this work the nitrate content of the alfalfa and oat soil is very low, while that of corn, potatoes, and fallow is higher. Lyon and Bizzell (37) in 1913 reviewed the work of other investigators and summarized their own work on the influence of higher plants on the formation of nitrates in the soil. From this they conclude that,

aside from the influence of cultivation, the source of greatest difference in the nitrates under various crops may be sought in the inherent differences in the plants of different species in their stimulating and inhibiting influence on the production of nitrates, as well as in their relative rates, amounts, and forms of nitrogen absorbed. Changes in the moisture content and temperature of the soil after early summer had no important effect on the nitrogen content of the soil under plants. On the uncropped soil an increase in moisture content was sometimes accompanied by an increase in nitrates and sometimes by a decrease. But, as pointed out by Kellerman and Wright (27), there may be a variation with different soils. But even the species of organisms found within the soil is controlled to a degree by the crop growing on the soil, as indicated by the work of Stoklasa and Vitek (58).

INFLUENCE OF SEASON

The season of the year has a marked influence upon the bacterial activities of the soil, but it is not necessarily correlated with the nitrate content of the soil. Schlœsing (50) found the nitrates in the drain water from both manured and unmanured soil high in spring, as compared with midsummer, fall, or winter, thus confirming the results obtained at the Rothamsted station. Shutt (53) reports nearly five times the quantity of nitrates in fallow and cropped soil during June as during November. He does, however, find more during June than during May. The exact season of the year at which the maximum nitrate content is reached will vary with a number of factors, chief amongst which is the kind of crop growing on the soil, for King and Whitson (29) found that the nitrates in the surface foot start in the spring comparatively low and increase rapidly until June 1 on clover and oat ground and until July on corn and potato ground. From these dates they fall more or less rapidly, and the work at the Utah Station (56) demonstrates conclusively that there is a seasonal variation depending upon temperature, crop, and quantity of irrigation water applied to the soil.

Moreover, André (1) has shown that the insoluble nitrogenous compounds of the surface soil are largely transformed into soluble compounds during the summer, and these are widely diffused through the deeper layers of soil during the winter, so that in the spring the lower layers of soil contain more soluble nitrogen than the surface soil. At the end of summer, however, the distribution is quite uniform. This finding has been amply verified by the results reported by Stewart and Greaves (56), Vel'bel (59), Jensen (26), and Lyon and Bizzell (34). These results will vary, however, with different soils, as shown by Russel (49), who reports the fluctuations in nitrates more marked on loams than on clay or sands; moreover, he found the bacterial activities much greater in early summer than later.

Moll (40) even goes so far as to claim from his work that the season of the year is the principal factor in determining the biochemical transformation in a soil, and Heinze (24) found that the number of organisms in a soil was highest in the summer months and lowest in the fall and spring. As already pointed out, the highest nitrifying power of a soil is not necessarily correlated with the highest nitrate content. The latter is highest in spring or early summer, while Vogel (62) found the former to be highest in October and November, after which there was a falling off until April, when it rose again, but not so high as in autumn. This corresponds fairly with the findings of Green (23) for the ammonifying powers of the soil. These findings, however, are contrary to those of Wojtkiewicz (66), who found the maximum number of organisms to occur in soil during the spring and the minimum in the winter. He also notes a correlation between the bacteria present and the amount of nitrates in the soil.

Inasmuch as we have taken no samples while the soil was frozen, no attempt has been made to review the literature dealing with this very interesting phase of the subject.

EXPERIMENTAL WORK

NATURE OF THE EXPERIMENTAL FIELD

The investigations were conducted on the Greenville farm, belonging to the Utah Experiment Station, which is located 2 miles north of the college farm. The soil of the farm is of a sedimentary nature, being derived from the weathering of the mountain range near by, which consists largely of limestone, quartzite, and dolomite. At the time of Lake Bonneville (19) the mountain streams poured their waters, loaded with the weatherings of these rocks, in the various stages of subdivision (gravel, sand, and silt) into the still waters of the lake. When the swiftly running water of the stream met the quiet water of the lake, the stream began to deposit its load. The gravel and coarser material being deposited first, gave rise to the well-defined deltas found at the mouths of all the larger streams. One of the best defined deltas is that on which the old college farm is located. The fine material, consisting mainly of fine sand, silt, and clay, was carried out farther into the lake, where it was gradually deposited. It is of this sedimentary material that the Greenville farm is composed.

At the beginning of the investigation a soil survey was made of the farm in the following manner: Samples of soil were taken in foot sections from each plot, the corresponding foot sections of these samples were thoroughly mixed and taken to the chemical laboratory, where they were subjected to chemical and physical analyses.

Table II gives the chemical composition of the soil to the depth of 8 feet. The method of analysis followed was that advocated by the Association of Official Agricultural Chemists (65).

TABLE II.—*Chemical composition of the soil of the Greenville (Utah) farm*

Constituent.	Depth of soil.							
	1st foot.	2d foot.	3d foot.	4th foot.	5th foot.	6th foot.	7th foot.	8th foot.
Insoluble residue	41.46	35.57	31.65	40.90	28.38	29.22	30.57	30.33
Soluble silica	.62	.84	.41	.75	.34	.42	.57	.42
Total	42.08	36.41	32.06	41.65	28.72	29.64	31.14	30.75
Potash (K_2O)	.67	.89	.59	.82	.61	.74	.79	.75
Soda (Na_2O)	.35	.47	.47	.62	.37	.42	.45	.74
Lime (CaO)	16.88	17.80	21.34	15.60	22.62	23.15	22.21	21.78
Magnesia (MgO)	6.10	9.46	7.57	7.48	9.36	5.89	6.06	5.63
Iron oxide (Fe_2O_3)	3.03	2.69	3.46	2.95	2.17	2.42	2.47	2.54
Alumina (Al_2O_3)	5.64	4.69	3.40	6.09	5.33	8.07	7.90	9.03
Phosphoric acid (P_2O_5)	.41	.29	.34	.19	.12	.06	.07	.11
Carbon dioxid (CO_2)	19.83	23.11	26.67	20.88	29.31	29.57	28.80	28.13
Volatile matter	5.60	3.38	3.93	4.23	.91	.95	......	.24
Total	100.69	99.29	99.93	100.51	99.52	100.91	99.92	99.68
Humus	.53	1.00	.61	.47	1.13	.60	.44	.57
Nitrogen	.139	.117	.080	.175	.072	.070	.062	.066

An examination of Table II will show that we have here a soil, like all of our Utah soils, exceptionally rich in the essential plant foods. The potassium is equally as high in the eighth and intermediate feet as in the first foot. The phosphoric acid is high in the first foot but gradually decreases in each succeeding foot. The humus and nitrogen, as is characteristic of the soils of arid America, are low. One of the most important considerations, however, from the viewpoint of this investigation, is the fact that the calcium and magnesium carbonate content of the soil is exceptionally high. In fact, the results indicate that 43 per cent of the surface foot of soil is calcium and magnesium carbonate and that the amount increases with depth to the fifth foot, after which the magnesium content is practically the same as in the first foot, while the calcium carbonate also increases with depth to a maximum in the fifth foot and then remains practically constant.

From the work of previous investigators on the magnesia content of soils one would conclude that the soil would be sterile, but just the contrary is true—the soil is remarkably fertile and produces excellent crops even without the addition of barnyard manure. With the single exception of its low humus content, the soil is ideally adapted both chemically and bacteriologically to support rapid bacterial action.

Table III gives the physical composition of the soil of the Greenville farm. The results show the soil to be a good loam of remarkable uniformity throughout the 8 feet.

TABLE III.—*Physical analysis of the soil of the Greenville (Utah) farm*

Item.	Depth of soil.							
	1st foot.	2d foot.	3d foot.	4th foot.	5th foot.	6th foot.	7th foot.	8th foot.
Coarse sand	0.21	0.17	0.68	1.02	0.09	0.34	0.47	0.09
Medium sand	9.63	8.29	6.63	9.63	9.53	9.48	8.91	7.08
Fine sand	30.04	32.54	29.49	33.06	36.92	33.79	35.34	34.25
Coarse silt	32.25	32.81	32.62	28.51	28.65	30.49	31.65	32.65
Medium silt	12.30	10.46	10.89	10.95	10.46	10.85	9.92	9.89
Fine silt	6.25	4.81	7.27	6.94	4.85	5.86	5.56	5.84
Clay	7.62	7.12	10.13	7.52	7.82	6.78	6.52	7.57
Moisture	1.60	1.47	1.13	1.49	.95	1.01	1.01	.84
Soluble and lost	.10	2.33	1.16	.83	.73	1.40	1.42	1.99
Specific gravity	2.67	2.72	2.80	2.69	2.76	2.79	2.71	2.76
Apparent sp. gr.	1.23	1.27	1.30	1.29	1.33	1.34	1.39	1.35
Water-soluble salts	.06	.11	.14	.16	.08	.09	.15	.09

PLAN OF EXPERIMENT

The experimental field was divided into 20 plots one-twenty-sixth of an acre in area. Each plot was leveled and banked up around edges, so that the water applied would distribute itself equally over the entire area of the plot.

Leading to each series of plots were wooden lateral flumes, so arranged that the measured water could be accurately applied. The plan of the field and the distribution of the laterals are shown in figure 1.

The field was divided into five equal sets of plots. The first set was left fallow, the second was planted to alfalfa, the third was planted to corn, the fourth was planted to potatoes, and the fifth was planted to oats. One of these sets received a maximum, one a medium, one a minimum application of water, and one set was unirrigated. The plots were sampled during the spring (about the middle of April), midsummer (about the last of July), and in the fall (the last of October or the first of November). The samples were analyzed for moisture, nitric nitrogen, number of bacteria developing on synthetic media, and the ammonifying and nitrifying powers. The irrigation and sampling were so arranged that results from the cropped irrigated plots could be compared with the unirrigated plot of the same series and also with the fallow plots receiving a corresponding amount of irrigation water.

The arrangement of the plots, crop growing upon each, and amount of water applied during the last nine years are indicated below:

(*a*) ALFALFA:

Plot 31G, 37.5 inches of water applied in five equal irrigations.
Plot 32G, 25 inches of water applied in five equal irrigations.
Plot 33G, 15 inches of water applied in five equal irrigations.
Plot 34G, unirrigated.

(*b*) POTATOES:

Plot 35G, 37.5 inches of water applied in five equal irrigations.
Plot 36G, 25 inches of water applied in five equal irrigations.
Plot 37G, 15 inches of water applied in five equal irrigations.
Plot 38G, unirrigated.

(c) FALLOW:

Plot 39G, 37.5 inches of water applied in five equal irrigations.
Plot 40G, 25 inches of water applied in five equal irrigations.
Plot 41G, 15 inches of water applied in five equal irrigations.
Plot 42G, unirrigated.

(d) OATS:

Plot 43G, 37.5 inches of water applied in five equal irrigations.
Plot 44G, 25 inches of water applied in five equal irrigations.
Plot 45G, 15 inches of water applied in five equal irrigations.
Plot 46G, unirrigated.

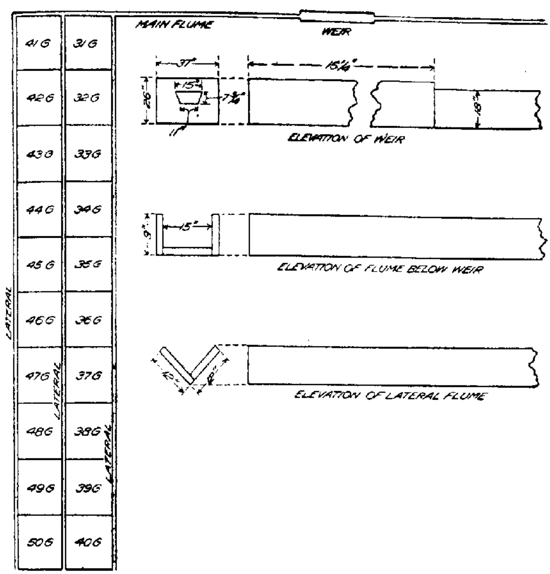

FIG. 1.—Plan of plots 30 G to 50 G, Greenville farm, showing main flume and laterals.

(e) CORN:

Plot 47G, 37.5 inches of water applied in five equal irrigations.
Plot 48G, 25 inches of water applied in five equal irrigations.
Plot 49G, 15 inches of water applied in five equal irrigations.
Plot 50G, unirrigated.

In the work it was desired to eliminate, as far as possible, all variable factors except crop and irrigation water. For this reason the depth of plowing, time of planting, cultivation, etc. were as nearly uniform as possible on all of the plots.

METHOD OF SAMPLING

For the determination of nitric nitrogen samples of soil were taken in foot sections to a depth of 6 feet, by means of a King soil tube. Single samples were taken from as near the center of the plot as possible, care being taken that separate borings were at least 3 feet apart. The samples thus obtained were taken to the chemical laboratory, where nitric nitrogen and moisture determinations were made immediately upon the samples. The results reported here, therefore, are all referred to moisture-free basis.

For the bacteriological work all possible precautions were taken, when collecting the samples, against the contamination of one sample by another. The surface soil to a depth of half an inch was scraped off by means of a sterile spade. A hole 12 inches deep was dug, and a slice of soil to this depth was taken from the side of the hole and placed in a sterile mixing pan. This process was repeated from four or five places in the field, and then the contents of the pan was carefully mixed by means of a sterile spatula. From this composite sample a representative portion, about 5 pounds of soil, was placed in a sterile ore sack and conveyed to the laboratory for analysis.

Before each sampling, the spade, mixing pan, and spatula were all carefully sterilized by heat from a plumber's torch, thus preventing the transfer of organisms from one soil to another. The samples were immediately transferred to the laboratory, partly air-dried in the dark, and then ground in a sterile mortar, all coarse rock being removed. The analysis was begun in all cases within 24 hours of the time of taking samples.

METHODS OF ANALYSIS

The soil extract for the determination of nitric nitrogen was obtained by means of the Pasteur-Chamberland filter. For rapid work a series of 24 Pasteur-Chamberland filters was arranged together and connected to a tank of compressed air filled by means of an air pump run by a ½ horsepower electric motor. Fifty gm. portions of the soil were triturated in a mortar with 250 c. c. of distilled water, and 2 gm. of quicklime for 2 minutes, allowed to settle 20 minutes, and then filtered through the Pasteur-Chamberland filter. By this method a clear, colorless filtrate was readily obtained.

An aliquot portion (50 c. c.) was immediately measured into 100-c. c. beakers and evaporated to dryness on the electric hot plate. The residue was treated with 1 c. c. of phenol-disulphonic acid equally distributed over it, and then allowed to stand for 10 minutes. This solution was diluted with water and the excess of acid neutralized with dilute ammonia. The color produced was compared with that produced by a standard solution of potassium nitrate treated in the same manner. The quantity

of chlorids in the soil solution was not sufficient to affect the sensitiveness of the method (55).

The number of organisms was determined by growing them on a modified synthetic agar having the following composition:

1,000 c. c. of distilled water.
10 gm. of dextrose.
0.5 gm. of dipotassium phosphate (K_2HPO_4).
0.2 gm. of magnesium sulphate ($MgSO_4$).
2 gm. of powdered agar per 100 c. c. of media.

After the samples of soil had been carefully mixed by shaking, 100 gm. were weighed on a sterile watch glass, using a small sterile spatula. This soil was transferred to 200 c. c. of sterile water and shaken for one minute, 1 c. c. of this suspension transferred to 99 c. c. of sterile water, and the dilution continued with 9 c. c. of sterile water. The plates were made so as to give a dilution of 1 to 20,000 and 1 to 200,000. They were incubated at 28° C. for four days and then counted. No attempt was made to differentiate between bacteria and molds, but all were listed together as total numbers of colonies.

The ammonifying power of the soil was determined by weighing 100-gm. portions of the soil and 2 gm. of dried blood into sterile tumblers and covering them with petri dishes. The dried blood was thoroughly mixed with the soil by means of a sterile spatula and the water content made up to 18 per cent with sterile water. The samples were incubated at 28° to 30° C. for four days and the ammonia determined by transferring to Kjeldahl flasks with 250 c. c. of distilled water, adding 2 gm. of magnesium oxid and distilling into *N/10* sulphuric acid. The determinations were all made in duplicates and compared with sterile blanks.

The nitrifying power of the soils was determined in tumblers like the ammonifying power, except that they were incubated for 21 days. The moisture content was made up weekly to the initial 18 per cent.

At the end of the incubation period each soil was transferred with 250 c. c. of distilled water to a 1-pint Mason fruit jar. Two gm. of powdered lime were added and the jar placed in the shaking machine for 10 minutes, after which it stood in the closed jar until clear. This never required over two hours. At the end of this time an aliquot part (100 c. c.) was measured into a flask and the nitrates determined by the aluminum reduction method (4).

The soil on which the experiments were conducted is extremely fertile, as is shown by the fact that the soil has been cropped for 48 years without the addition of barnyard manure or commercial fertilizers, yet during the last 4 years it has yielded fair crops. This is shown in Table IV, which gives the average yearly yield in pounds per acre. From these yields and the average percentage of nitrogen in the crops under similar irrigated conditions (64) the average amount of nitrogen removed per year has been calculated.

TABLE IV.—*Average yield of dry matter and nitrogen from the experimental plots on Greenville farm*

[Expressed as pounds per acre]

Water applied.	Alfalfa.			Potatoes.		
	Plot No.	Hay.	Nitrogen.	Plot No.	Tubers.	Nitrogen.
Inches.						
37.5	31	10,464	282.5	35	1,464	20.4
25.0	32	9,963	265.0	36	1,540	24.8
15.0	33	9,779	259.1	37	1,759	33.2
None	34	6,808	170.1	38	1,075	19.1

Water applied.	Oats.				Corn.			
	Plot No.	Grain.	Straw.	Nitrogen.	Plot No.	Grain.	Stover.	Nitrogen.
Inches.								
37.5	43	2,273	2,989	89.5	47	2,080	3,316	66.3
25.0	44	2,093	2,581	83.9	48	1,995	3,332	69.6
15.0	45	1,885	1,821	71.7	49	2,179	3,605	76.6
None	46	1,560	1,928	64.0	50	1,600	3,280	62.3

INFLUENCE OF WATER ON THE NITRIC NITROGEN OF THE SOIL

The results obtained by a direct determination of the nitric nitrogen of the soil have been so arranged that the plots growing each specific crop but receiving different quantities of irrigation water are placed in the same table. This makes it possible to directly compare the plots receiving varying quantities—37.5, 25, and 15 inches of irrigation water—with each other and each of these in turn with the unirrigated plot. The results are reported as pounds per acre and are the average for three years. The plots were sampled in the spring (May 1), midsummer (August 1), and in the fall (November 28).

1.—ALFALFA LAND

There were four plots in this series, one receiving 37.5 inches of irrigation water, one 25 inches, one 15 inches, and one was unirrigated. The average results expressed as pounds per acre are given in Table V.

During the spring and summer the nitric nitrogen is about uniformly distributed throughout the 6 feet of soil, but in the fall it has become concentrated in the surface 2 feet. The difference in the nitric-nitrogen content of the soil of the various plots between fall and spring is quite significant, for the plots which had received no irrigation water throughout the season are richer in nitric nitrogen in the spring than in the fall, while all of the irrigated plots are much richer in the fall than in the spring. This is likely due to the moist conditions of the irrigated plots in the fall, as the winter rains would carry the soluble constituents of

these plots to a greater depth than they would in the unirrigated. This conclusion is borne out by the results previously published by us (56). In this earlier work we took samples to a depth of 10 feet and found that there is no loss of nitric nitrogen from these plots during the winter months, thus showing that the nitric nitrogen is carried below the 6-foot level.

TABLE V.—*Nitric nitrogen in alfalfa land—Average for three years*

[Results expressed as pounds per acre]

Plot No.	Period.	Water applied in five applications.	Depth of soil.						Total.
			1st foot.	2d foot.	3d foot.	4th foot.	5th foot.	6th foot.	
		Inches.							
31	Spring	37.5	3.6	1.9	0.6	2.0	1.4	1.0	10.5
32	...do	25.0	1.9	2.0	1.8	1.4	2.5	1.4	11.0
33	...do	15.0	3.4	.9	11.6	3.3	1.6	1.9	22.7
34	...do	None.	10.9	5.1	11.4	2.2	9.3	6.0	44.9
31	Summer	37.5	7.1	2.5	2.5	1.9	2.1	.4	16.5
32	...do	25.0	2.4	3.2	2.3	1.8	1.4	1.5	12.6
33	...do	15.0	5.4	.8	2.1	1.7	3.1	1.4	15.1
34	...do	None.	3.3	8.8	2.2	1.4	2.6	1.0	19.3
31	Fall	37.5	8.5	4.2	2.4	3.5	2.8	2.0	23.4
32	...do	25.0	14.9	9.0	3.2	2.4	2.0	4.4	35.9
33	...do	15.0	10.7	10.4	4.4	2.3	2.9	1.8	32.5
34	...do	None.	19.5	9.7	6.5	3.0	2.1	1.1	41.9

The results at first glance might be taken to indicate that the application of irrigation water to this soil has retarded nitrification, but it must be borne in mind that the nitrogen removed from the irrigated plots was much greater than that removed from the unirrigated plot. This nitrogen must come either directly from the air through the intervention of lower organisms or from the soluble nitrates of the soil. The evidence is practically conclusive that the alfalfa plant feeds upon the latter as long as it is available and only turns to the atmospheric nitrogen when the soil supply has been reduced to a certain low minimum.

The quantity of nitric nitrogen in the soil decreases as the quantity of water applied increases, and this is much more pronounced in the spring than it is in the summer or fall. But the influence of the irrigation water is quite noticeable throughout the year. The results as a whole clearly indicate that the nitric nitrogen of the alfalfa soil is low throughout the season, in spite of the fact that the alfalfa is capable of indirectly drawing upon the atmospheric nitrogen. The nitrogen found within the alfalfa removed from these plots comes from a number of sources—the atmospheric nitrogen, the nitrogen contained within the 6 feet of soil, and nitrogen from a depth greater than 6 feet. A comparison of these results with those reported where the soil was sampled to a depth of 10 feet makes the conclusion practically certain that much nitric nitrogen

has been brought up from below 6 feet. It is also interesting to note that, while the total nitrogen disappearing from each plot bears a relationship to the water applied, the quantity per inch of water is greatest where only 15 inches of water were applied. In fact, it is twice as great as where 37.5 inches of water are applied to the soil (Table VI).

TABLE VI.—*Summary of nitrogen transformations in alfalfa soil*

[Results expressed in pounds]

Character of nitrogen.	Water applied.			
	37.5 inches.	25 inches.	15 inches.	None.
Nitrogen removed in crop	282.5	265	259.1	170.1
Nitrogen in soil in spring	10.5	11	22.7	44.9
Nitrogen in soil in fall	23.4	35.9	32.5	41.9
Original soil nitrogen removed	−12.9	−24.9	−9.8	3.0
Nitrogen formed during season	295.4	289.9	268.9	167.1
Excess of nitrogen formed during season in the irrigated plots	128.3	122.8	101.8	....
Excess per acre-inch of water	3.4	4.9	6.8	....

2.—POTATO LAND

The plots in the series on potato land were four in number. One received 37.5 inches, one 25 inches, one 15 inches of irrigation water, while one was unirrigated. All other conditions of the plots were kept as nearly uniform as possible, so that any difference which is found to exist in the nitric nitrogen must be due to the variable factor—the water applied. The average results for the three years are given in Table VII.

TABLE VII.—*Nitric nitrogen in potato land—Average for three years*

[Results expressed as pounds per acre]

Plot No.	Period.	Water applied in five applications.	Depth of soil.						
			1st foot.	2d foot.	3d foot.	4th foot.	5th foot.	6th foot.	Total.
		Inches.							
35	Spring	37.5	11.4	12.2	2.3	2.7	2.2	2.9	33.7
36	...do	25.0	17.1	8.2	8.9	7.9	5.0	2.8	49.9
37	...do	15.0	20.5	8.7	4.0	4.0	3.1	4.0	44.3
38	...do	None.	10.9	29.0	43.6	46.4	38.5	27.9	196.3
35	Summer	37.5	2.6	2.0	12.8	7.9	8.4	4.3	38.0
36	...do	25.0	9.8	4.4	8.9	6.3	6.7	8.3	44.4
37	...do	15.0	16.1	15.2	7.2	3.2	3.0	2.4	47.1
38	...do	None.	25.9	8.9	17.5	25.1	18.4	17.9	113.7
35	Fall	37.5	9.9	6.1	3.7	4.9	3.0	3.9	31.5
36	...do	25.0	18.9	5.5	6.2	7.9	5.2	4.2	47.9
37	...do	15.0	10.9	3.7	2.5	6.6	7.2	4.4	35.3
38	...do	None.	34.6	17.6	9.8	11.5	19.1	9.6	102.2

The nitric nitrogen in the surface foot of all these plots is very high during the spring and fall. In the summer they are high only in the plots which received 15 inches and no irrigation water, thus showing the effect of the water upon the soluble nitrates of the soil. In all of the irrigated plots the total nitric nitrogen found in the soil at the end of the season is practically the same as in the spring. But the unirrigated plot, between the fall and spring sampling, gains 94 pounds of nitric nitrogen. Now, if this be a correct measure of the nitric nitrogen produced by the various plots during the winter and spring months, there must have been large quantities of the nitric nitrogen which was produced in the irrigated soil carried below 6 feet. It is not likely that the water content of the irrigated plots would have become sufficient to retard nitrification to this extent, although it may have been retarded to a degree by the lower temperature which would prevail in the heavily irrigated plots. But this would be far from sufficient to account for the excess quantity of nitrates found in the unirrigated soil. Much of this, therefore, must have disappeared in the drain waters.

The influence of the irrigation water upon the nitric-nitrogen content of the soil is noticeable throughout the year, and the quantity present at any time decreases as the proportion of water applied to the soil increases. It is interesting to compare the total nitric nitrogen of the various plots in spring and fall with that removed by the crop under the various treatments (Table VIII).

TABLE VIII.—*Summary of nitrogen transformations in potato land*

[Results expressed in pounds]

Character of nitrogen.	Water applied.			
	37.5 inches.	25 inches.	15 inches.	None.
Nitrogen removed in crop	20.4	24.8	33.2	19.1
Nitric nitrogen in soil in spring	33.7	49.9	44.3	196.3
Nitric nitrogen in soil in fall	31.5	47.9	35.3	102.2
Original nitric nitrogen removed from soil	2.2	2.0	9.0	94.1
Nitric nitrogen formed during season	18.2	22.8	24.2	−75.0
Excess of nitric nitrogen formed during season in irrigated soil	93.2	97.8	99.2	....
Excess per acre-inch of water applied	2.5	3.9	6.6	....

This gives the best results both for total quantity of water applied and quantity per inch of water where an application of 15 inches of water is used. Furthermore, these results indicate that one of two things must have occurred in these plots: Either the formation of nitric nitrogen has been increased to a greater extent than shown by these results by the irrigation water, or else the water has carried none to a greater depth than 6 feet. And all of our results have pointed strongly

to the conclusion that this latter assumption is not the correct one. Hence, the quantity which has been formed, due to the irrigation water, must be larger than is here indicated. The large quantity of nitric nitrogen which has disappeared from the unirrigated plot during the summer could not have been due to denitrification, for there was nothing in the conditions of this plot which would favor the denitrification, the quantity of organic matter present was low, and the aeration would be better than in the irrigated soil. The only conditions which could in any way favor it are larger quantities of nitrates present, and these may favor the rapid growth of other organisms. Furthermore, our results show the existence of many more organisms in this unirrigated plot during the spring than there are in any of the other plots on which potatoes were grown. Hence, the most reasonable explanation is that the nitrates disappeared because the bacterial flora of the soil had transformed them into proteins in their metabolic processes.

3.—OAT LAND

There were four plots in this series and the water applied and method of application were the same as in the previous series. The average results for the three years are given in Table IX.

TABLE IX.—*Nitric nitrogen in oat land—Average for three years*

[Results expressed as pounds per acre]

Plot No.	Period.	Water applied in five applications.	Depth of soil.						
			1st foot.	2d foot.	3d foot.	4th foot.	5th foot.	6th foot.	Total.
		Inches.							
43	Spring	37.5	13.7	4.3	5.9	1.8	3.4	2.6	31.7
44	do	25.0	15.8	4.9	3.4	5.3	1.8	4.3	35.5
45	do	15.0	7.6	6.9	9.6	4.6	1.7	3.0	33.4
46	do	None.	9.1	5.9	4.0	6.1	10.7	6.3	42.1
43	Summer	37.5	2.2	2.0	3.2	1.2	1.9	1.8	12.1
44	do	25.0	2.6	1.7	3.2	2.8	2.4	3.3	16.0
45	do	15.0	5.1	3.8	3.7	1.7	3.0	.8	18.1
46	do	None.	3.3	1.6	1.5	1.6	1.6	.8	10.4
43	Fall	37.5	5.6	3.0	4.0	2.8	2.5	2.5	20.4
44	do	25.0	4.0	3.2	3.0	2.7	2.8	2.6	18.3
45	do	15.0	4.2	3.3	4.1	3.4	2.9	2.7	20.0
46	do	None.	6.7	3.9	3.7	3.3	2.9	2.8	23.3

The nitric nitrogen in all of the oat plots is quite uniform during the spring, but by midsummer the large accumulations of the surface foot have disappeared. This may be due to the leaching out of the nitrates by the irrigation water, or the rapidly growing plant may have utilized it. Very likely it is due to the latter factor, for the loss is nearly uniform from the irrigated and unirrigated plots. The only change which

we note in the fall is an accumulation of more nitrates in the surface feet. It is interesting to note that each plot gains considerable nitric nitrogen during the winter months. The gain is least in the plot which received 37.5 inches of water, but is quite uniform in each of the others.

The summarized results of the nitrogen removed in the crop, together with the original nitric nitrogen present in the soil and the amount formed during the irrigation season, are recorded in Table X.

TABLE X.—*Summary of nitrogen transformations in oat land*

[Results expressed in pounds]

Character of nitrogen.	Water applied.			
	37.5 inches.	25 inches.	15 inches.	None.
Nitrogen removed in crop	89.5	83.9	71.7	64.0
Nitrogen in soil in spring	31.7	35.5	33.4	42.1
Nitrogen in soil in fall	20.4	18.3	20.6	23.3
Original soil nitrogen removed	11.3	17.2	12.8	18.8
Nitrogen formed during season	78.2	66.7	58.9	45.2
Excess of nitric nitrogen in irrigated plots	33.0	21.5	13.7	......
Excess per acre-inch of water	.88	.86	.91	......

From this it may be seen that the greatest quantity of nitric nitrogen was produced in the plot which received the greatest quantity of water, but the amount per acre-inch of water is slightly higher in the plot which received only 15 inches of water. The actual difference in the quantity of nitrogen produced in the various plots would be even greater than the figures herein represent them to be, for the tendency would be for the larger quantities of water to carry some of the nitric nitrogen below the sixth foot. It is important to note that the order of effectiveness was found by us to be practically the same as here reported when we sampled the plots to a depth of 10 feet; yet in this work they are more regular than in previously reported results.

4.—CORN LAND

There were four plots in this series. One received 37.5 inches of water, one 25 inches, one 15 inches, and one was unirrigated. With the exception of the amounts of water applied, the plots were all uniformly handled throughout the experiment. The average results for the three years are given in Table XI.

The nitric nitrogen is high in the surface foot of all the plots in the spring. This is especially the case where only 15 inches or no irrigation water was applied, but in the summer it becomes very low. This is due mainly to the removal of the nitric nitrogen by the rapidly growing plant. The water, however, does play some part, for we find that the nitric nitrogen of the surface foot disappears more rapidly from the

irrigated plots than from the unirrigated plot. This difference is very marked if we compare the results obtained on the plot receiving 37.5 inches of water, with the plot receiving no water for summer and fall. The quantity found in the surface foot of the unirrigated plot is about the same in the fall as in the spring, while the irrigated contains less than half as much.

TABLE XI.—*Nitric nitrogen in corn land—Average for three years*

[Results expressed as pounds per acre]

Plot No.	Period.	Water applied (five applications).	Depth of soil.						
			1st foot.	2d foot.	3d foot.	4th foot.	5th foot.	6th foot.	Total.
		Inches.							
47	Spring	37.5	9.1	3.4	3.3	2.1	1.7	4.2	23.8
48	...do	25.0	7.2	2.3	2.0	1.9	1.9	2.2	17.5
49	...do	15.0	12.3	8.5	4.1	2.0	1.6	1.9	30.4
50	...do	None.	12.0	4.1	1.9	2.5	3.4	3.5	27.4
47	Summer	27.5	1.2	2.9	8.5	4.1	4.0	1.4	22.1
48	...do	25.0	1.7	1.6	5.5	3.9	1.9	2.2	16.8
49	...do	15.0	1.4	5.2	3.7	2.5	3.2	3.3	19.3
50	...do	None.	3.3	3.1	2.9	2.6	3.2	2.2	17.3
47	Fall	37.5	3.0	3.6	2.7	2.0	2.7	2.4	16.4
48	...do	25.0	3.7	3.0	2.2	2.7	2.4	3.2	17.2
49	...do	15.0	5.8	2.5	3.2	3.0	3.2	3.2	20.9
50	...do	None.	11.2	4.6	3.1	3.5	5.0	5.9	33.3

The total quantity found in the various plots in the spring is nearly the same as that found in them during the fall. A summarized inventory of the nitrogen removed by the crop, together with that formed in the various plots, is given in Table XII. Here we note a decrease in the nitrogen removed in the crop, as the water applied increases above 15 inches. This can be accounted for by the larger quantities of water washing the nitric nitrogen beyond the sphere of action of the roots, thus making the nitrogen the limiting factor.

TABLE XII.—*Summary of nitrogen transformations in corn land*

[Results expressed in pounds of nitric nitrogen per acre-inch]

Character of nitrogen.	Water applied.			
	37.5 inches.	25 inches.	15 inches.	None.
Nitrogen removed in crop	66.3	69.6	76.6	62.3
Nitrogen in soil in spring	23.8	17.5	30.4	27.4
Nitrogen in soil in fall	16.4	17.2	20.9	33.3
Original soil nitrogen removed	7.4	.3	9.5	−5.9
Nitrogen formed during season	58.9	69.3	67.1	68.2

These results would lead us to believe that the quantity of nitric nitrogen formed during the season was much less where 37.5 inches of water were applied than where 25 inches, 15 inches, and no water was used. This is probably not correct, but in this plot much nitric nitrogen has been removed in the drain waters. This set of plots differs markedly from all others, in that no more nitric nitrogen is accounted for in the irrigated than in the nonirrigated soil. Nor do these results correspond with those previously published by us; however, the variation may be due to the difference in depth of sampling, for in previously reported results we have sampled to a depth of 10 feet, while here we have sampled to a depth of only 6. In this latter case, apparently, the total herein reported does not represent all the nitric nitrogen formed within the soil; but during the summer, where the heavier applications of irrigation water are made, much of the nitric nitrogen is carried below 6 feet.

5.—FALLOW SOIL

Four plots were kept fallow throughout the experiment. One of these received 37.5 inches of water, one 25 inches, one 15 inches, while one was unirrigated. With the exception of water applied, the plots were all treated the same. The summarized results for the three years, reported as pounds per acre, are given in Table XIII.

TABLE XIII.—*Nitric nitrogen in fallow land—average for three years*

[Results expressed as pounds per acre]

Plot No.	Period.	Water applied (five applications).	Depth of soil.						Total.
			1st foot.	2d foot.	3d foot.	4th foot.	5th foot.	6th foot.	
		Inches.							
39	Spring	37.5	15.6	14.5	10.7	5.5	7.2	5.9	59.4
40	do	25.0	10.1	6.0	4.8	5.5	10.5	19.4	56.3
41	do	15.0	10.4	15.6	9.2	9.1	13.6	9.5	67.4
42	do	None.	18.9	39.6	31.9	14.8	21.7	16.1	143.0
39	Summer	37.5	4.8	6.9	5.3	9.4	8.6	7.2	42.2
40	do	25.0	3.5	13.4	13.1	15.2	10.6	7.9	72.7
41	do	15.0	8.4	6.2	14.4	2.6	2.1	3.1	26.8
42	do	None.	15.5	9.7	8.2	9.7	13.6	16.1	72.8
39	Fall	37.5	9.4	7.2	7.8	9.0	6.3	5.3	45.0
40	do	25.0	16.5	7.9	9.7	6.0	7.8	4.5	52.4
41	do	15.0	10.1	7.4	6.3	7.2	7.7	7.3	46.0
42	do	None.	31.5	17.6	18.1	15.9	11.5	12.3	106.9

The quantity of nitric nitrogen in the surface foot of all the plots is high in the spring but greatly decreases in the surface foot of all the irrigated plots in the summer. There is, however, a reconcentration of the nitric nitrogen in the surface during the fall. This is very pronounced in the case of the plot which did not receive irrigation water. The total quantity of nitric nitrogen in each specific plot is higher in the spring

than in the fall, thus showing a gain for the winter months and a loss for the summer months. This loss can not be due to the water applied, because it is most pronounced in the unirrigated plots and probably represents the quantity transferred into complex proteins by the bacteria. Taken as a whole, the results would tend to indicate that the irrigation water had decreased, instead of accelerating the formation of nitric nitrogen in these plots. When we take the average total amount of nitric nitrogen in all cropped and fallow plots receiving the same amount of irrigation water, we note a pronounced difference in the quantity of nitric nitrogen in the plots receiving varying quantities of water. These averages are given in Table XIV.

TABLE XIV.—*Average quantity of nitric nitrogen found in the plots receiving the various amounts of irrigation water*

[Results expressed as pounds]

Water applied (inches).	Spring.	Summer.	Fall.	Average.
37.5	31.8	26.2	27.3	28.4
25.0	34.0	32.5	34.3	33.6
15.0	39.6	25.3	31.1	32.0
None	90.7	46.7	61.5	66.3

The quantity of nitric nitrogen found within the surface 6 feet of soil decreases as the water applied increases. The difference is very noticeable in all of the plots in the spring. During the summer and fall all irrigated plots tend to reach a similar concentration of nitric nitrogen. But even then there is twice as much in the unirrigated as in the irrigated, and during the spring there is three times as much in the nonirrigated as in the plot receiving 37.5 inches of water.

In previously reported work (56) we have shown that the application of irrigation water increases the quantity of nitric nitrogen actually formed within the soil; hence, the difference between that found within the irrigated and the unirrigated soils must represent the quantity removed by the crop plus that washed to a region below 6 feet in the soil. These results prove conclusively that this is no small quantity, especially when large quantities of water are applied to the soil. Hence, the excessive use of irrigation water is not only a waste but it decreases the yield upon a given soil; and this latter effect is due in all probability to the rapid removal of the soluble nitrates beyond the reach of the growing plant.

INFLUENCE OF THE CROP ON THE NITROGEN OF THE SOIL

The experiment was so planned that it would also give information on the influence of crop upon the nitric nitrogen of the soil. Therefore, the results have been rearranged so as to compare plots receiving the same quantity of water but growing different crops. In these the variable is the crop, while the water remains a constant.

PLOTS RECEIVING 37.5 INCHES OF IRRIGATION WATER

In this series we have alfalfa, potato, oat, corn, and fallow plots, each receiving 37.5 inches of irrigation water, so that any difference noted in the nitric nitrogen of the soil must be due either directly or indirectly to the crop growing upon the same. The summarized results for the three years are given in Table XV.

TABLE XV.—*Nitric nitrogen in soil growing various crops and receiving 37.5 inches of irrigation water—Average for three years*

[Results expressed as pounds per acre]

Period.	Crop.	Depth of soil.						Total.
		1st foot.	2d foot.	3d foot.	4th foot.	5th foot.	6th foot.	
Spring..........	Alfalfa..........	3.6	1.9	0.6	2.0	1.4	1.0	10.5
Do..........	Oats..........	13.7	4.3	5.9	1.8	3.4	2.6	31.7
Do..........	Corn..........	9.1	3.4	3.3	2.1	1.7	4.2	23.8
Do..........	Potatoes..........	11.4	12.2	2.3	2.7	2.2	2.9	33.7
Do..........	Fallow..........	15.6	14.5	10.7	5.5	7.2	5.9	59.4
Summer..........	Alfalfa..........	7.1	2.5	2.5	1.9	2.1	.4	16.5
Do..........	Oats..........	2.2	2.0	3.2	1.2	1.9	1.8	12.1
Do..........	Corn..........	1.2	2.9	8.5	4.1	4.0	1.4	22.1
Do..........	Potatoes..........	2.6	2.0	12.8	7.9	8.4	4.3	38.0
Do..........	Fallow..........	4.8	6.9	5.3	9.4	8.6	7.2	42.2
Fall..........	Alfalfa..........	8.5	4.2	2.4	3.5	2.8	2.0	23.4
Do..........	Oats..........	5.6	3.0	4.0	2.8	2.5	2.5	20.4
Do..........	Corn..........	3.0	3.6	2.7	2.0	2.7	2.4	16.4
Do..........	Potatoes..........	9.9	6.1	3.7	4.9	3.0	3.9	31.5
Do..........	Fallow..........	9.4	7.2	7.8	9.0	6.3	5.3	45.0

There is a marked difference in the quantity and distribution of the nitric nitrogen found in the soils growing the various crops. During the spring the nitric-nitrogen content of the surface feet of the alfalfa and corn land is comparatively low, while that of the oat, potato, and fallow soil is high. This is especially marked in the case of the last two, for here we find over one-half of the total existing within the 6 feet found within the first two. But in the summer the nitric nitrogen is carried to lower depths by the irrigation water, only to concentrate at the surface again during the fall. The total quantity of nitric nitrogen in the alfalfa, oat, and corn soil is low throughout the year, while the quantity in the potato and fallow is comparatively high. It is interesting to note that, in spite of the heavy drain which has been made upon the soil-growing crops, the nitric nitrogen in the soil during the fall is nearly the same as during the spring, while the fallow soil shows a loss of 14.4 pounds during summer. This is probably due to the water carrying the nitric nitrogen below 6 feet, and the results herein reported point strongly to the conclusion that the continuous application of 37.5 inches of irrigation water to a soil yearly is going to result in the loss of considerable nitrogen from that soil.

If we assume that all of the nitrogen which is removed by the oats or corn is nitrified before removal and then compare these results with those obtained on the fallow soil, we find that the fallow soil is short 77 pounds of nitric nitrogen. This quantity minus the extra quantity formed, due to the stimulating action of the plant upon the nitrifying organisms, may be taken as the minimum quantity which is leached out of this plot during the season or converted into other forms by bacteria. The loss from leaching in the case of the cropped plots would be much lower, but even here the loss from leaching where excessive quantities of water are used is considerable.

PLOTS RECEIVING 25 INCHES OF IRRIGATION WATER

There were five plots in this series, so arranged that the cropped plots can be compared with each other, and these in turn with the fallow. Since the treatment which the plots in this series have received, such as plowing, cultivation, etc., has been as nearly uniform as possible, the variable is the crop. The marked difference, therefore, in the several plots must be due to the influence of the crop upon the movement and production of nitric nitrogen. The average results for the three years are given in Table XVI.

TABLE XVI.—*Nitric nitrogen in soil with various crops and receiving 25 inches of irrigation water—Average for three years*

[Results expressed in pounds per acre]

Period.	Crop.	Depth of soil.						Total.
		1st foot.	2d foot.	3d foot.	4th foot.	5th foot.	6th foot.	
Spring	Alfalfa	1.9	2.0	1.8	1.4	2.5	1.4	11.0
Do	Oats	15.8	4.9	3.4	5.3	1.8	4.3	35.5
Do	Corn	7.2	2.3	2.0	1.9	1.9	2.2	17.5
Do	Potatoes	17.1	8.2	8.9	7.9	5.0	2.8	49.9
Do	Fallow	10.0	6.0	4.8	5.5	10.5	19.4	56.3
Summer	Alfalfa	2.4	3.2	2.3	1.8	1.4	1.5	12.6
Do	Oats	2.6	1.7	3.2	2.8	2.4	3.3	16.0
Do	Corn	1.7	1.6	5.5	3.9	1.9	2.2	16.8
Do	Potatoes	9.8	4.4	8.9	6.3	6.7	8.3	44.4
Do	Fallow	3.5	13.4	13.1	15.2	19.6	7.9	72.7
Fall	Alfalfa	14.9	9.0	3.2	2.4	2.0	4.4	35.9
Do	Oats	4.0	3.2	3.0	2.7	2.8	2.6	18.3
Do	Corn	3.7	3.0	2.2	2.7	2.4	3.2	17.2
Do	Potatoes	18.9	5.5	6.2	7.9	5.2	4.2	47.9
Do	Fallow	16.5	7.9	9.7	6.0	7.8	4.5	52.4

It may be seen that during the spring the nitric nitrogen of the alfalfa soil is very low, and the quantity present is about equally distributed throughout the 6 feet, while in the other plots the total quantity is much higher. Especially is this true in the potato and fallow soil, and we

find the greater part of it concentrated in the surface-foot sections. During the summer it is more evenly distributed throughout the 6 feet. The fallow gains considerable nitric nitrogen during the early summer, while each of the other soils shows a loss, which in the case of the oat soil is quite pronounced. Prior to the summer sampling it appears that the water applied has not been sufficient to carry much of the nitric nitrogen below the sixth foot, but during the time which elapsed between the summer and fall sampling there was a loss from the fallow soil, with a slight gain in each of the other soils. Moreover, these results, taken in connection with those previously published by us, where samples were taken to a depth of 10 feet, indicate that no small quantity of the nitric nitrogen is carried below the sixth-foot level. Hence, the continuous use of this quantity of water on these plots would result in an unnecessary loss of nitric nitrogen from the soil. The fallow, potato, and corn land contains practically the same quantity of nitric nitrogen in the soil during the spring as during the fall, while the alfalfa and oats show a wide variation.

PLOTS RECEIVING 15 INCHES OF IRRIGATION WATER

Each of the plots in this series received 15 inches of irrigation water. The treatment of each plot was as nearly similar as compatible with the various crops growing upon them; hence, any difference in nitric nitrogen noted should be due to the crops. The average summarized results for the three years are given in Table XVII.

TABLE XVII.—*Nitric nitrogen in soil with various crops and receiving 15 inches of irrigation water—Average for three years*

[Results expressed as pounds per acre]

Period.	Crop.	Depth of soil.						Total.
		1st foot.	2d foot.	3d foot.	4th foot.	5th foot.	6th foot.	
Spring	Alfalfa	3.4	0.9	11.6	3.3	1.6	1.9	22.7
Do	Oats	7.6	6.9	9.6	4.6	1.7	3.0	33.4
Do	Corn	12.3	8.5	4.1	2.0	1.6	1.9	30.4
Do	Potatoes	20.5	8.7	4.0	4.0	5.1	4.0	44.3
Do	Fallow	10.4	15.6	9.2	9.1	13.6	9.5	67.4
Summer	Alfalfa	5.4	.8	2.1	1.7	3.1	1.4	15.1
Do	Oats	5.1	3.8	3.7	1.7	3.0	.8	18.1
Do	Corn	1.4	5.2	3.7	2.5	3.2	3.3	19.3
Do	Potatoes	16.1	15.2	7.2	3.2	3.0	2.4	47.1
Do	Fallow	8.4	6.2	4.4	2.6	2.1	3.1	26.8
Fall	Alfalfa	10.7	10.4	4.4	2.3	2.9	1.8	32.5
Do	Oats	4.2	3.3	4.1	3.4	2.9	2.7	20.6
Do	Corn	5.8	2.5	3.2	3.0	3.2	3.2	20.9
Do	Potatoes	10.9	3.7	2.5	6.6	7.2	4.4	35.3
Do	Fallow	10.1	7.4	6.3	7.2	7.7	7.3	46.0

The quantity of nitric nitrogen found in the alfalfa and oat soil is low during the spring and it is quite evenly distributed throughout the 6 feet, while the corn, potato, and fallow soil is exceptionally high in nitric nitrogen in the first foot. The total quantity of nitric nitrogen in the potato and fallow soil throughout the season is higher than in the other plots, but in the case of the fallow there is a marked decrease in the total nitric nitrogen of the soil. This must be due to the action of bacteria in transforming the nitrates into protein material within the soil, because it is not likely that this quantity of water would be sufficient to carry the nitric nitrogen beyond the 6 feet. Furthermore, if we compare the nitrates found in the soil for the last three years with those for the previous eight years, we find that during the last three years the total quantity of nitric nitrogen in the 6 feet of soil is one-third lower than it was during the first period, showing a decrease in the nitric nitrogen of fallow soil. Whether this can be due to a decrease in the total nitrogen of the soil or merely to a decrease in the nitrifying powers of the soil can not be answered with the data at hand. There is the possibility that in the presence of large quantities of nitrates there may be developed a strain of bacteria which would rapidly transform the ammonia and nitrates into protein material. It does not seem possible that any great quantity of the nitrogen could have disappeared through denitrification, for the soil is well aerated and the quantity of organic matter present is extremely low.

PLOTS RECEIVING NO IRRIGATION WATER

All of the plots in this series were treated as nearly uniform as possible. The oats and alfalfa plots were not cultivated. The plots were unirrigated, and the marked difference in the nitric nitrogen of the various plots is probably due to the crop factor. The average summarized results for the three years are given in Table XVIII.

The nitric nitrogen of all the unirrigated plots is comparatively high in the spring, decreases in the summer, and increases in the fall. The greatest decrease occurs in those plots having the greatest accumulation of nitrates. In the potato plots the unaccounted-for nitrates amount to 82.6 pounds per acre, only slightly greater than in the fallow, which shows a loss of 71.2 pounds. The fact that this loss is so pronounced in the fallow soil shows that it is not due to the removal of the nitric nitrogen by the growing plants. The fact that it is so rapidly regained during the winter months clearly indicates that it is not due to water removing the soluble nitrates; nor is it due to denitrification, for these plots are as high in total nitrogen as are others which have not shown this seasonal loss of nitrates. The probable explanation of the phenomena which we have so continuously observed in these plots is the following. The accumulation of large quantities of nitrates in the soil depresses to a degree the speed with which the nitrifying organisms act, but it increases

the speed with which the protein-forming organisms work. Furthermore, while the increased temperature of summer increases the activity of both classes of organisms, the speed of the latter is accelerated to a much greater extent by heat than is the speed of the former. Moreover, both classes of organisms are sensitive to cold, but it would appear that those which bring about synthetic reactions are much more sensitive than are those which bring about the analytic change. We therefore have an accumulation of nitrates during the cold seasons and a disappearance during the warmer months of the year. These facts would be in keeping with the findings of Conn, Brown, and others who have noticed that cold increases the nitrifying powers of the soil.

TABLE XVIII.—*Nitric nitrogen in soil with various crops and receiving no irrigation water—Average for three years*

[Results expressed as pounds per acre]

Period.	Crop.	Depth of soil.						Total.
		1st foot.	2d foot.	3d foot.	4th foot.	5th foot.	6th foot.	
Spring	Alfalfa	10.9	5.1	11.4	2.2	9.3	6.0	44.9
Do	Oats	9.1	5.9	4.0	6.1	10.7	6.3	42.1
Do	Corn	12.0	4.1	1.9	2.5	3.4	3.5	27.4
Do	Potatoes	10.9	29.0	43.6	46.4	38.5	27.9	196.3
Do	Fallow	18.9	39.6	31.9	14.8	21.7	16.1	143.0
Summer	Alfalfa	3.3	8.8	2.2	1.4	2.6	1.0	19.3
Do	Oats	3.3	1.6	1.5	1.6	1.6	.8	10.4
Do	Corn	3.3	3.1	2.9	2.6	3.2	2.2	17.3
Do	Potatoes	25.9	8.9	17.5	25.1	18.4	17.9	113.7
Do	Fallow	15.5	9.7	8.2	9.7	13.6	16.1	72.8
Fall	Alfalfa	19.5	7.0	6.5	3.0	2.1	1.1	39.2
Do	Oats	6.7	3.9	3.7	3.3	2.9	2.8	23.3
Do	Corn	11.2	4.6	3.1	3.5	5.0	5.9	33.3
Do	Potatoes	34.6	17.6	9.8	11.5	19.1	9.6	102.2
Do	Fallow	31.5	17.6	18.1	15.9	11.5	12.3	106.9

If we average the nitric nitrogen in the plots growing the various crops, we find a marked difference in the quantity found in the various plots (Table XIX).

TABLE XIX.—*Average nitric nitrogen in the plots growing various crops*

[Results expressed as pounds per acre]

Crop.	Time of sampling.			Average.
	Spring.	Summer.	Fall.	
Alfalfa	22.3	15.8	32.8	23.6
Oats	35.7	14.1	20.6	23.5
Corn	24.8	18.9	22.0	21.9
Potatoes	81.1	60.8	54.2	65.3
Fallow	81.5	53.6	62.6	65.9

Here we find a much smaller quantity of nitric nitrogen in all the plots during the summer than during either spring or fall; and with one exception, the alfalfa, it is lower in the fall than in the spring. During the summer months we find the alfalfa and oats much closer feeders on the nitric nitrogen of the soil than are the other plants. However, the average quantity of nitric nitrogen found in the 6 feet of soil for the season on the alfalfa, oat, and corn soil is nearly the same in each case. This appears to contradict the conclusions previously reached by us; but it must be borne in mind that in the previous work our samples were taken to a depth of 10 feet, and a comparison of the two sets of results indicates that the alfalfa and oats, besides being closer feeders upon nitric nitrogen, feed to a greater depth than do the other crops. Furthermore, it makes it very certain that in a study of the nitric nitrogen of a soil, such as used in these experiments, samples must be taken to a great depth; otherwise erroneous conclusions will be drawn from the results obtained.

It is interesting to note that throughout the season there is over twice the nitric nitrogen in the potato and fallow soil than in any of the other soils, and even these plots show a decrease in nitric nitrogen during summer and fall. There is a slight difference in favor of the fallow plots in the fall, but in the spring the quantity in both sets is the same.

COMPOSITION OF THE SOIL SOLUTION

Moisture determinations were made on each soil at time of sampling so the results could be calculated to a dry basis. From the results obtained for nitric nitrogen and soil moisture, it is possible to calculate the concentration of the soil solution. While this has been done for each individual plot, only the summarized results are reported in Tables XX and XXI, and they represent the average for all the determinations covering these years.

TABLE XX.—*Concentration of the soil solution growing various crops*

[Results reported as nitric nitrogen parts per million of soil solution]

Crop.	First foot.	Second foot.	Third foot.	Fourth foot.	Fifth foot.	Sixth foot.	Average.
Alfalfa	16.0	10.8	9.8	5.2	6.7	4.7	8.87
Oats	14.0	7.6	8.7	6.8	7.0	6.4	8.92
Corn	13.3	7.7	7.5	6.2	6.9	6.6	8.03
Potatoes	32.6	21.6	22.3	24.0	24.1	15.2	23.28
Fallow	26.4	25.3	23.5	18.7	20.6	19.7	22.38

It is interesting to note the great difference between the concentration of the soil solution of the alfalfa and potato soils. The average concentration of the alfalfa, oat, and corn land is about the same, while the potato and fallow is the same. However, there is a slight difference in

the concentration of the surface foot in favor of the potato soil. But these results show conclusively that the soil solution is influenced to a depth of at least 6 feet by the crop grown upon it.

TABLE XXI.—*Concentration of the soil solution where various quantities of water have been applied*

[Results reported as nitric nitrogen parts per million of soil solution]

Water applied (inches).	First foot.	Second foot.	Third foot.	Fourth foot.	Fifth foot.	Sixth foot.	Average.
37.5	14.2	9.9	10.0	8.2	8.1	6.7	9.5
25	19.7	10.2	10.4	10.4	10.5	11.6	12.1
15	16.8	13.4	11.2	8.1	8.6	7.2	10.9
None	35.6	27.5	28.0	25.2	30.0	24.8	28.5

The concentration of the soil solution varies with the quantity of water applied to the soil during the season. It is three times as concentrated in the soil which received no irrigation water as in the soil which received 37.5 inches; but the difference is not great between the concentration of the heaviest irrigated soil and those which received much smaller quantities of water.

INFLUENCE OF WATER ON THE NUMBER OF ORGANISMS AND ON THE AMMONIFYING AND NITRIFYING POWERS OF THE SOIL

All of the plots which have been considered in the previous discussion were sampled, and bacteriological analyses made of the soils. The samples for this work were taken on the same day in the spring, midsummer, and fall as were the samples for the direct chemical analyses. These, however, were taken to a depth of only 12 inches. Three individual determinations were made at each sampling during each season for the three years, so each result as reported, unless stated to the contrary, represents the average of nine or more analyses. Determinations were made of the number of organisms developing upon synthetic agar, the ammonifying powers, and the nitrifying powers of the soil. The results have been so arranged that we can compare the soil from each of the plots receiving the various quantities of water with each other and these in turn with the unirrigated. Furthermore, it is possible to compare directly the number of organisms, ammonia, and nitric nitrogen produced, as all are reported in the same table (Table XXII).

ALFALFA

There were four plots in the alfalfa series. These received varying quantities of water; otherwise, they were all treated alike. To one plot were applied 37.5 inches of water; to another, 25 inches; to a third, 15 inches, while one was unirrigated. The average results for the three years are given in Table XXII.

TABLE XXII.—*Number of colonies of bacteria, milligrams of ammonia, and milligrams of nitric nitrogen from soil receiving varying amounts of water. Crop, alfalfa. Average for three years*

Plot No.	Water applied.	Sampled May 1.	Sampled Aug. 1.	Sampled Nov. 28.	Average.
NUMBER OF COLONIES OF BACTERIA DEVELOPED IN 4 DAYS ON SYNTHETIC AGAR PER GRAM OF SOIL					
	Inches.				
31	37.5	6,700,000	6,433,000	2,800,000	5,311,000
32	25.0	8,933,000	7,066,000	4,933,000	6,977,000
33	15.0	9,466,000	6,566,000	4,600,000	6,877,000
34	None.	8,133,000	6,333,000	5,667,000	6,711,000
MILLIGRAMS OF AMMONIA PRODUCED IN 100 GM. OF SOIL IN 4 DAYS					
31	37.5	50.5	46.0	42.2	46.2
32	25.0	49.9	51.2	39.0	46.7
33	15.0	51.9	52.8	35.2	46.6
34	None.	53.5	52.7	43.0	49.7
MILLIGRAMS OF NITRIC NITROGEN PRODUCED IN 100 GM. OF SOIL IN 21 DAYS					
31	37.5	3.7	9.9	1.9	5.2
32	25.0	2.7	8.6	3.7	5.0
33	15.0	4.7	5.2	3.6	4.5
34	None.	1.5	6.2	3.1	3.6

The number of organisms in this soil which develop on synthetic agar is greater in May than in August or November. In all the plots there was a gradual decrease from spring to fall. This difference is greatest in those plots which received the most water. The number of organisms is greatest in the soil which received no water and least in the soil which received 37.5 inches of water. In every instance during spring and fall the number of organisms decreases as the water applied increases; and the difference is so marked and regular that it seems safe to attribute it to the water applied. During the summer the difference in the number of organisms in the various plots is not great; especially is this true in the irrigated plots.

The ammonifying powers of all the soils are highest in spring and lowest in fall. The difference in the quantity of ammonia produced in the various soils is not great. But during the spring and summer the ammonifying powers of each soil decrease as the water applied increases. The difference is not regular in the fall; but from all the results it seems quite certain that the addition of irrigation water to alfalfa soil, such as used in this investigation, causes a decrease in the ammonifying powers of the same.

The nitrifying powers of all the soils are higher in midsummer and lower in the fall and spring. This difference is very pronounced in the soil

receiving the greatest quantities of water. During the spring and summer the nitrifying powers of the soil are quite regularly increased by the irrigation water. But apparently the water in the soil where the 37.5 inches are being applied toward fall becomes sufficient to depress greatly its ammonifying powers. This, however, may be due to the continual washing of the nitrifying organisms to below 12 inches.

There is a marked relationship between the number of organisms and the ammonifying powers of the soil, but the nitrifying powers show no relationship to either.

POTATO LAND

The plots in this series were each planted to potatoes, and all received the same cultivation and general treatment, with the exception of water applied, which varied from no irrigation to 37.5 inches per year. The average results for the three years are given in Table XXIII.

TABLE XXIII.—*Number of colonies of bacteria, milligrams of ammonia, and milligrams of nitric nitrogen from soil receiving varying amounts of water. Crop, potatoes. Average for three years*

NUMBER OF COLONIES DEVELOPED IN 4 DAYS ON SYNTHETIC AGAR PER GRAM OF SOIL

Plot No.	Water applied.	Sampled May 1.	Sampled Aug. 1.	Sampled Nov. 28.	Average.
	Inches.				
35	37.5	4,933,000	5,766,000	4,533,000	5,077,000
36	25.0	5,666,000	7,000,000	4,000,000	5,555,000
37	15.0	5,833,000	5,067,000	4,800,000	5,233,000
38	None.	7,167,000	6,500,000	5,833,000	6,500,000

MILLIGRAMS OF AMMONIA PRODUCED IN 100 GM. OF SOIL IN 4 DAYS

Plot No.	Water applied.	Sampled May 1.	Sampled Aug. 1.	Sampled Nov. 28.	Average.
35	37.5	50.3	67.9	53.3	57.2
36	25.0	63.0	66.3	48.5	59.2
37	15.0	51.2	57.4	38.7	49.1
38	None.	56.4	65.0	50.6	57.3

MILLIGRAMS OF NITRIC NITROGEN PRODUCED IN 100 GM. OF SOIL IN 21 DAYS

Plot No.	Water applied.	Sampled May 1.	Sampled Aug. 1.	Sampled Nov. 28.	Average.
35	37.5	4.0	10.2	2.2	5.5
36	25.0	4.3	17.8	10.4	10.8
37	15.0	2.6	20.6	6.0	9.7
38	None.	1.1	13.6	3.8	6.2

The relationship between the water applied and the number of bacteria is not as well defined in the potato as in the alfalfa soil; but even in the potato plots the tendency is for the larger quantities of water to depress the number of bacteria. The number of organisms is slightly higher in the spring than in the fall, and the difference which is noted in the fall appears again in the spring. The number found in the summer is considerably higher than the number found in either fall or spring. The results as a whole indicate that the water has decreased the number of organisms in the first foot.

During the spring the ammonifying power of the soil which had received 25 inches of water is considerably higher than any of the others, while in the fall and summer the soil which received 37.5 inches of water is the greatest. The results collectively indicate that the irrigation water has increased the ammonifying powers of the potato soil. The ammonifying powers of all the plots are higher in summer than in either spring or fall.

The nitrifying powers of the soil are much higher in summer than either fall or spring, and there is a relationship between the water applied and the nitrifying powers of the soil. The water increases the nitrifying powers of the soil. The highest results were obtained where 25 inches of water were applied.

For the potato land we note a decrease in the number of organisms as the water applied increases, but an increase in both ammonifying and nitrifying powers with increased water. So it would appear that the water has increased the physiological efficiency of the organisms without increasing the number.

OAT LAND

The oat plots received 37.5 inches, 25 inches, 15 inches, and no water. Otherwise they were all treated the same. The average results for the three years are given in Table XXIV.

TABLE XXIV.—*Number of colonies of bacteria, milligrams of ammonia, and milligrams of nitric nitrogen from soil receiving varying amounts of water. Crop, oats. Average for 3 years*

NUMBER OF COLONIES DEVELOPED IN 4 DAYS ON SYNTHETIC AGAR PER GRAM OF SOIL

Plot No.	Water applied.	Sampled May 1.	Sampled Aug. 1.	Sampled Nov. 28.	Average.
	Inches.				
43	37.5	6,133,000	6,000,000	4,133,000	5,422,000
44	25.0	5,700,000	4,800,000	2,866,000	4,455,000
45	15.0	6,200,000	5,133,000	4,400,000	5,244,000
46	None.	7,533,000	5,967,000	6,000,000	6,500,000

MILLIGRAMS OF AMMONIA PRODUCED IN 100 GM. OF SOIL IN 4 DAYS

43	37.5	56.8	69.3	49.6	58.6
44	25.0	53.3	56.3	52.1	53.9
45	15.0	48.0	55.4	46.0	49.8
46	None.	48.8	50.2	44.7	47.9

MILLIGRAMS OF NITRIC NITROGEN PRODUCED IN 100 GM. OF SOIL IN 21 DAYS

43	37.5	1.7	3.9	2.1	2.6
44	25.0	2.2	4.7	.8	2.6
45	15.0	1.7	2.0	2.3	2.0
46	None.	4.0	5.4	6.8	5.4

In every case the number of organisms is greater in the oat soil during the spring than in summer or fall, and with one exception they are greater in summer than in fall. While the difference is not as great nor as regular as might be desired, the tendency seems to be for the water to depress the number of organisms in oat soil.

The ammonifying powers of the soil is higher in the summer than in the fall or spring, and there is a pronounced and regular difference between those receiving the various quantities of irrigation water in favor of those receiving the greatest quantity. While the difference is considerable throughout the season, it is more pronounced in the summer than at the time of taking the other samples. From an examination of the nitrification series one sees that this apparent increase in ammonia, due to water, may be caused in part by the depression of the nitrifying organisms, for the application of irrigation water to these soils has depressed the nitrifying powers of the soil. This is quite pronounced at each season, and appears in the results for each specific year. Hence, it must be attributed to the water applied.

CORN LAND

The four corn plots in this series received 37.5 inches, 25 inches, 15 inches, and no irrigation water. Otherwise, they were all handled the same. The average summarized results for the three years are given in Table XXV.

TABLE XXV.—*Number of colonies of bacteria, milligrams of ammonia, and milligram of nitric nitrogen from soil receiving varying amounts of water. Crop, corn. Average for 3 years*

Plot No.	Water applied.	Sampled May 1.	Sampled Aug. 1.	Sampled Nov. 28.	Average.
NUMBER OF COLONIES DEVELOPED IN 4 DAYS ON SYNTHETIC AGAR PER GRAM OF SOIL					
	Inches.				
47	37.5	6,700,000	6,866,000	3,333,000	5,633,000
48	25.0	4,600,000	5,800,000	3,366,000	4,589,000
49	15.0	5,933,000	6,133,000	2,967,000	5,011,000
50	None.	6,100,000	3,867,000	4,767,000	4,911,000
MILLIGRAMS OF AMMONIA PRODUCED IN 100 GM. OF SOIL IN 4 DAYS					
47	37.5	50.5	59.1	46.7	52.1
48	25.0	55.2	55.8	44.4	51.8
49	15.0	50.5	61.5	43.2	51.7
50	None.	55.2	57.2	46.6	53.0
MILLIGRAMS OF NITRIC NITROGEN PRODUCED IN 100 GM. OF SOIL IN 21 DAYS					
47	37.5	2.6	7.6	1.5	3.9
48	25.0	1.9	2.1	0.5	1.5
49	15.0	2.3	2.2	2.4	2.3
50	None.	1.9	2.1	1.5	1.8

The number of organisms in the corn soil is highest in summer and lowest in the fall. But during spring and fall there would appear to be no relationship between the water applied and number of organisms. However, in the summer there is a very pronounced difference in favor of the plots receiving the greatest quantity of water, and this regularity is found in each season's results.

The results obtained for ammonification are very irregular, but it is interesting to note that they in every case have almost a quantitative relationship to the results obtained with the potatoes.

Nitrification is slightly higher in the summer than during either of the other seasons, and it would appear that the irrigation water had increased the nitrifying powers.

FALLOW SOIL

The fallow plots received the same quantity of water as the cropped plots and were plowed and handled the same. Any weeds which appeared during the summer were pulled. The average summarized results for the three years are given in Table XXVI.

TABLE XXVI.—*Number of colonies of bacteria, milligrams of ammonia, and milligrams of nitric nitrogen from soil receiving varying amounts of water. Crop, fallow. Average for three years*

NUMBER OF COLONIES DEVELOPED IN 4 DAYS ON SYNTHETIC AGAR PER GRAM OF SOIL

Plot No.	Water applied.	Sampled May 1.	Sampled Aug. 1.	Sampled Nov. 28.	Average.
	Inches.				
39	37.5	8,266,000	6,933,000	2,200,000	5,800,000
40	25.0	3,300,000	3,370,000	3,700,000	3,457,000
41	15.0	4,867,000	3,967,000	2,533,000	3,789,000
42	None.	3,100,000	3,633,000	1,767,000	2,833,000

MILLIGRAMS OF AMMONIA PRODUCED IN 100 GM. OF SOIL IN 4 DAYS

Plot No.	Water applied.	Sampled May 1.	Sampled Aug. 1.	Sampled Nov. 28.	Average.
39	37.5	66.2	69.4	49.6	61.7
40	25.0	66.8	80.1	56.1	67.7
41	15.0	61.5	76.8	46.5	61.6
42	None.	61.2	56.7	52.6	56.8

MILLIGRAMS OF NITRIC NITROGEN PRODUCED IN 100 GM. OF SOIL IN 21 DAYS.

Plot No.	Water applied.	Sampled May 1.	Sampled Aug. 1.	Sampled Nov. 28.	Average.
39	37.5	1.5	8.7	1.1	3.7
40	25.0	.6	2.0	1.5	1.3
41	15.0	1.5	3.6	3.1	2.7
42	None.	1.6	7.7	4.2	4.5

The number of organisms in these plots is highest in spring and lowest in fall, and they show an increase due to the irrigation water used. The ammonifying powers are highest in summer and lowest in fall, and the water applied increases the ammonifying power and is greatest where 25 inches are applied. The 37.5 inches, while they are better than none, depress the ammonifying powers when compared with 25 inches.

It was thought likely that this decrease in the nitrifying powers and formation of nitric nitrogen in these plots with highest water content may be due to a difference in temperature. For this reason temperature determinations were made on the soil during September and October of one season. The determinations were made to a depth of 4 feet with soil thermometers placed in the ground and read twice daily, at 8 a. m. and 5 p. m. The average results for the season are given in Table XXVII, expressed in degrees Fahrenheit.

TABLE XXVII.—*Average temperature (°F.) of the soil at different depths*

Plot.	Time.	First foot.	Second foot.	Third foot.	Fourth foot.
39	8 a. m.	54.8	52.1	49.9	47.2
	5 p. m.	55.1	52.3	49.8	48.7
40	8 a. m.	53.9	52.6	47.4	....
	5 p. m.	53.9	52.7	48.9	....
41	8 a. m.	54.3	53.3	51.8	49.1
	5 p. m.	54.7	53.1	51.7	49.4
43	8 a. m.	56.5	55.4	52.8	50.3
	5 p. m.	56.8	55.6	52.6	51.2

This table shows that the temperature is about 2 degrees higher in the nonirrigated soil than in the soil receiving the greatest quantity of water; and the difference is about the same even in the fourth foot, which has a temperature about 6 degrees lower than the temperature of the surface soil. The temperature of the soil is only slightly different in morning and evening, but the difference extends to a depth of 4 feet.

The nitrifying powers are highest in midsummer, at which time they are apparently increased by the irrigation water, but are depressed by the larger quantities in the fall.

The results which we have considered indicate that the irrigation water applied has clearly depressed the number of organisms which develop upon synthetic agar in alfalfa, oats, and potato soil. The results obtained for the corn are not regular, but there is a marked increase in the fallow.

The ammonifying powers were increased in all of the soils except the alfalfa, and in this case there was a decrease.

The nitrifying powers have been increased in every case except in the oat soil. The average results for the different water treatments are given in Table XXVIII.

TABLE XXVIII.—*Average bacterial activities in soil with various water treatments*

NUMBER OF COLONIES OF BACTERIA

Water applied (inches).	Spring.	Summer.	Fall.	Average.
37.5	6, 546, 000	7, 600, 000	3, 400, 000	5, 849, 000
25.0	5, 640, 000	5, 606, 000	3, 773, 000	5, 006, 000
15.0	6, 260, 000	5, 173, 000	3, 860, 000	5, 098, 000
None	6, 206, 600	6, 060, 000	4, 807, 000	5, 691, 000

MILLIGRAMS OF AMMONIA PRODUCED IN 100 GM. OF SOIL

37.5	54.8	62.3	46.3	54.5
25.0	57.2	61.9	48.0	55.7
15.0	52.6	60.8	40.9	51.4
None	55.0	58.2	47.5	53.6

MILLIGRAMS OF NITRIC NITROGEN PRODUCED IN 100 GM. OF SOIL

37.5	2.7	8.4	1.7	4.3
25.0	2.3	7.0	3.4	4.2
15.0	2.5	6.7	3.8	4.3
None	2.0	7.0	3.9	4.3

If we take all the results into consideration, it is clear that the irrigation water had increased all of the bacterial activities of the soil; but it will be noted that the numbers of organisms, the ammonifying powers, and nitrifying powers of all the plots are extremely low; and it would appear that in all these plots the limiting factor is the organic matter. Had there been more organic matter present, the effect of the water would have been more pronounced, as it was found by one of us (21) in other experiments to be the case.

Furthermore, the difference which actually exists in the bacterial activities must have been greater than is brought out by these results, for during one season we made determinations of the number of organisms in the soil, and the ammonifying powers and the nitrifying powers of the soil both the day before irrigation and the day after irrigation. The results for the day before irrigation averaged one-fourth higher than did the results for the day after irrigation, thus clearly indicating that many of the organisms and the different species in about the same proportion had been carried below the first foot by the irrigation waters. This being the case, in order that an increase for the bacterial activities for the season is obtained, the remaining organisms must have multiplied much faster, or their physiological efficiency have become much greater in the irrigated than in the unirrigated. There is the possibility that the organisms would rapidly be brought to the sur-

face again by the water, but we could not expect this to be as great for the bacteria as it is for the soluble nitrates, and it has been seen that, even in the case of these where the greater quantities of water were used, the nitrates never concentrate in the surface foot during the summer, the results showing a decrease in most plots, due to water. It is therefore quite reasonable to expect that bacteria which developed upon synthetic agar would be carried down in about the same proportions as were the other organisms; hence, the increased bacterial activities noted must be due to an increased physiological efficiency of the organisms. Moreover, had samples been taken to a depth of 3 feet for the bacteriological analysis, we would have obtained just as pronounced an effect upon number of colonies of bacteria, ammonifying, and nitrifying powers of the soil as we have in the case of the nitrates, which is the summation effect noted in the 6 feet.

During the first season determinations were made of the nitrogen-fixing powers of the soil, but during the succeeding years we were so crowded with other work that it became impossible to continue this phase of the work. While the results for one season are not sufficient to warrant their consideration in detail, the average results are of interest, as they show the best fixation where 15 inches of water were applied to the soil. The averages for the various treatments were as follows:

37.5 inches of water......1.4 mgm. of nitrogen fixed in 100 gm. of soil.
25 inches of water........2.1 mgm. of nitrogen fixed in 100 gm. of soil.
15 inches of water........8.5 mgm. of nitrogen fixed in 100 gm. of soil.
None..................3.5 mgm. of nitrogen fixed in 100 gm. of soil.

INFLUENCE OF CROP WITH THE DIFFERENT QUANTITIES OF WATER ON BACTERIAL ACTIVITIES

The experiment was so planned that, besides giving information upon the influence of water upon the bacterial activities of the soil, it should also give definite information upon the influence of crop on these same properties. This being the case, the results have been rearranged so that the crop is the variable and the quantity of water a constant. We can therefore compare the results from the alfalfa with the various quantities of water with those obtained where other crops receiving like amounts of water were grown, and each of these in turn can be compared with the fallow.

PLOTS RECEIVING 37.5 INCHES OF IRRIGATION WATER

In this series the alfalfa, oats, corn, potato, and fallow soil each received 37.5 inches of irrigation water. The average summarized results for the three years are given in Table XXIX.

The number of organisms in the soil is greatest in the spring and least in the fall. During the spring the fallow has many more organisms than any of the cropped soils. During the summer the cropped and uncropped plots contain about the same number of organisms, while in the fall all

of the cropped plots contain a greater number of organisms than does the fallow, which would indicate that the limiting factor is more pronounced in its effect in fall on fallow soil than on cultivated soil.

TABLE XXIX.—*Number of colonies of bacteria, milligrams of ammonia, and milligrams of nitric nitrogen from soil with various crops receiving 37.5 inches of irrigation water*

NUMBER OF COLONIES DEVELOPED IN 4 DAYS ON SYNTHETIC AGAR

Plot No.	Crop.	Sampled May 1.	Sampled Aug. 1.	Sampled Nov. 28.	Average.
31	Alfalfa	6, 700, 000	6, 433, 000	2, 800, 000	5, 311, 000
43	Oats	6, 133, 000	6, 000, 000	4, 133, 000	5, 422, 000
47	Corn	6, 700, 000	6, 866, 000	3, 333, 000	5, 633, 000
35	Potatoes	4, 933, 000	5, 766, 000	4, 533, 000	5, 077, 000
39	Fallow	8, 266, 000	6, 933, 000	2, 200, 000	5, 799, 000
MILLIGRAMS OF AMMONIA PRODUCED IN 100 GM. OF SOIL IN 4 DAYS					
31	Alfalfa	50. 5	46. 0	43. 2	46. 6
43	Oats	56. 8	69. 3	49. 6	58. 6
47	Corn	50. 5	59. 1	46. 7	52. 1
35	Potatoes	50. 3	67. 9	53. 3	57. 1
39	Fallow	66. 2	69. 4	49. 6	61. 7
MILLIGRAMS OF NITRIC NITROGEN PRODUCED IN 100 GM. OF SOIL IN 21 DAYS					
31	Alfalfa	3. 7	9. 9	1. 9	5. 2
43	Oats	1. 7	3. 9	2. 1	2. 6
47	Corn	2. 6	7. 6	1. 5	3. 9
35	Potatoes	4. 0	10. 2	2. 2	5. 5
39	Fallow	1. 5	8. 7	1. 1	3. 7

The ammonifying powers of the soils are higher in summer than either spring or fall, and they are much higher in the fallow than in any of the cropped soils, the alfalfa being the lowest. In the fall the difference is not as marked, but even here the potato soil is the only one which has higher ammonifying powers than has the fallow. We thus find a close relationship between numbers and ammonifying powers of the soil. With the nitrifying powers we find no such regularity. Here the highest results are obtained with the potatoes, with the alfalfa a close second. Moreover, these results, if they represent what actually occurs in field conditions, indicate that the alfalfa must be removing the nitrogen from the soil much more rapidly than any of the other crops, for our previous results have taught us that the alfalfa is a close feeder upon the soluble nitric nitrogen of the soil, and now we find alfalfa soil nitrifying the organic material to a greater extent than do the other soils.

The low nitrifying powers of the oat soil is significant, as it indicates that the small quantities of nitric nitrogen found in this soil may be due in part to this factor.

PLOTS RECEIVING 25 INCHES OF IRRIGATION WATER

The four cropped plots and one fallow plot were in this series, and each received 25 inches of irrigation water during the season. The summarized results are given in Table XXX.

TABLE XXX.—*Number of colonies of bacteria, milligrams of ammonia, and milligrams of nitric nitrogen from soil with various crops receiving a medium application of water (25 inches)*

NUMBER OF COLONIES DEVELOPED IN 4 DAYS ON SYNTHETIC AGAR

Plot No.	Crop.	Sampled May 1.	Sampled Aug. 1.	Sampled Nov. 28.	Average.
32	Alfalfa	8,933,000	7,066,000	4,933,000	6,977,000
44	Oats	5,700,000	4,866,000	2,866,000	4,477,000
48	Corn	4,600,000	5,800,000	3,366,000	4,589,000
36	Potatoes	5,666,000	7,000,000	4,000,000	5,555,000
40	Fallow	3,300,000	3,370,000	3,700,000	3,457,000

MILLIGRAMS OF AMMONIA PRODUCED IN 100 GM. OF SOIL IN 4 DAYS

Plot No.	Crop.	Sampled May 1.	Sampled Aug. 1.	Sampled Nov. 28.	Average.
32	Alfalfa	47.9	51.2	39.0	46.0
44	Oats	53.3	56.3	52.1	53.9
48	Corn	55.2	55.8	44.4	51.8
36	Potatoes	63.0	66.3	48.5	59.2
40	Fallow	66.8	80.1	56.1	67.6

MILLIGRAMS OF NITRIC NITROGEN PRODUCED IN 100 GM. OF SOIL IN 21 DAYS

Plot No.	Crop.	Sampled May 1.	Sampled Aug. 1.	Sampled Nov. 28.	Average.
32	Alfalfa	2.7	8.6	3.7	5.0
44	Oats	2.2	4.7	.8	2.6
48	Corn	1.9	2.1	.5	1.5
36	Potatoes	4.3	17.8	10.4	10.8
40	Fallow	.6	2.0	1.5	1.3

The number of organisms in the alfalfa soil is very high during the spring and very low and uniform in the fallow throughout the year. The greatest difference in the plots is noted in the spring, the numbers being more nearly uniform during the summer; especially is this the case in the fall.

A very marked difference is noted in the ammonifying powers of the soils in favor of the fallow. Naming the plots in the order of increasing efficiency, we have alfalfa, oats, corn, potatoes, and fallow, which is about the order they have been maintaining in each series. And the difference is very pronounced in favor of the fallow soil. But we find the nitrifying powers of the fallow soil very low. In this series during the season it is high in the potato soil. The alfalfa is high compared with any of the other soils, thus showing that alfalfa soil has a high nitrifying power when compared with oats, corn, or even fallow.

PLOTS RECEIVING 15 INCHES OF IRRIGATION WATER

The treatments of these plots were, with the exception of the water applied (15 inches), the same as the previous series. The average results for the three years are given in Table XXXI.

TABLE XXXI.—*Number of colonies of bacteria, milligrams of ammonia, and milligrams of nitric nitrogen from soil with various crops receiving a minimum application of water (15 inches)*

NUMBER OF COLONIES DEVELOPED IN 4 DAYS ON SYNTHETIC AGAR

Plot No.	Crop.	Sampled May 1.	Sampled Aug. 1.	Sampled Nov. 28.	Average.
33	Alfalfa	9,466,000	6,566,000	4,600,000	6,877,000
45	Oats	6,200,000	5,133,000	4,400,000	5,244,000
49	Corn	5,933,000	6,133,000	2,967,000	5,011,000
37	Potatoes	5,833,000	5,067,000	4,800,000	5,233,000
41	Fallow	4,867,000	3,967,000	2,533,000	3,789,000

MILLIGRAMS OF AMMONIA PRODUCED IN 100 GM. OF SOIL IN 4 DAYS

Plot No.	Crop.	Sampled May 1.	Sampled Aug. 1.	Sampled Nov. 28.	Average.
33	Alfalfa	51.9	52.8	35.2	46.6
45	Oats	48.0	55.4	46.0	49.8
49	Corn	50.5	61.5	43.2	51.7
37	Potatoes	51.2	57.4	38.7	49.1
41	Fallow	61.5	76.8	46.5	61.6

MILLIGRAMS OF NITRIC NITROGEN PRODUCED IN 100 GM. OF SOIL IN 21 DAYS

Plot No.	Crop.	Sampled May 1.	Sampled Aug. 1.	Sampled Nov. 28.	Average.
33	Alfalfa	4.7	5.2	3.6	4.5
45	Oats	1.7	2.0	2.3	2.0
49	Corn	2.3	2.2	2.4	2.3
37	Potatoes	2.6	20.6	6.0	9.7
41	Fallow	1.5	3.6	3.1	2.7

Here, again, we find the greater number of organisms in the soil during the spring, with a great decrease during the fall. But the greatest number of organisms are found in the alfalfa and the least in the fallow.

The ammonifying powers of all the soils are highest in summer and lowest in fall. The fallow soil has a higher ammonifying efficiency than any of the others, which is the same as the order noted where the maximum quantity of water was applied to the soil.

The nitrifying powers of the fallow soil are very low, and of the alfalfa soil high, thus bearing out the observation made for the previous series. The quantity of nitrates produced by the potato soil during the summer and fall is very high, and is probably due in a degree to the cultivation received by these plots. It appears in all of the potato plots and not in the corn plots, which were also cultivated; hence, it must be due in a measure to the crop.

UNIRRIGATED SERIES

All of the crops which have appeared in the previous series, together with fallow, appear in the unirrigated series. The summarized results for the three years are given in Table XXXII.

TABLE XXXII.—*Number of colonies of bacteria, milligrams of ammonia, and milligrams of nitric nitrogen from soil with various crops receiving no irrigation water*

NUMBER OF COLONIES DEVELOPING IN 4 DAYS ON SYNTHETIC AGAR

Plot No.	Crop.	Sampled May 1.	Sampled Aug. 1.	Sampled Nov. 28.	Average.
34	Alfalfa	8,133,000	6,333,000	5,667,000	6,711,000
46	Oats	7,533,000	5,967,000	6,000,000	6,500,000
50	Corn	6,100,000	3,867,000	4,676,000	4,911,000
38	Potatoes	7,167,000	6,500,000	5,833,000	6,500,000
42	Fallow	3,100,000	3,633,000	1,767,000	2,833,000

MILLIGRAMS OF AMMONIA PRODUCED IN 100 GM. OF SOIL IN 4 DAYS

34	Alfalfa	53.5	52.7	43.0	49.7
46	Oats	48.8	50.2	44.7	47.9
50	Corn	55.2	57.2	46.6	53.0
38	Potatoes	56.4	65.0	50.6	57.3
42	Fallow	61.2	65.7	52.6	59.8

MILLIGRAMS OF NITRIC NITROGEN PRODUCED IN 100 GM. OF SOIL IN 21 DAYS

34	Alfalfa	1.5	6.2	3.1	3.6
46	Oats	4.0	5.4	6.8	5.4
50	Corn	1.9	2.1	1.5	1.8
38	Potatoes	1.1	13.6	3.8	6.2
42	Fallow	1.6	7.7	4.2	4.5

The organisms are highest in the alfalfa and lowest in the fallow soil throughout the year. With the exception of spring and summer for the series which received the maximum quantity of water, the alfalfa soil has been much higher in bacteria than any of the other soils. And in most of the series the decrease in number from spring to fall is much more pronounced in the fallow than in any of the cropped soils, thus indicating that something develops in the fallow soil during the summer which limits the number of organisms. However, it is not the water applied, for we find the decrease just as great in the unirrigated as in the irrigated soil. Furthermore, the results show conclusively that the crops have stimulated growth of organisms which will develop on synthetic agar. Considerable of this stimulation is produced by the plant residues which are left on the cropped soil but are missing from the fallow soil.

The ammonia produced by this series is highest in the fallow and considerably lower in the oats and alfalfa plots. The quantity produced in

the potato soil is only slightly lower than the quantity produced in the fallow, while the corn shows a slight decrease below the potato soil. As has been the tendency throughout each series, the ammonifying powers decrease considerably in the fall, and this decrease is greater in the fallow than in any of the cropped soils.

Here for the first time the fallow soil has a higher nitrifying power than the alfalfa soil. This is due to the difference in moisture content of the soil, for the unirrigated alfalfa plot became very dry during the summer and fall, while the fallow remained moist throughout the year. The very high nitrifying power of the potato soil is shown again in this series, making it certain that this is not due to accident but is characteristic of the potato plot.

The influence of crop upon the bacterial activities of the soil is emphasized in the result given in Table XXXIII, in which we have the average from all the plots receiving the different amounts of water.

TABLE XXXIII.—*Average bacterial activity of the soil as influenced by crop*

Crop.	Sampled May 1.	Sampled Aug. 1.	Sampled Nov. 28.	Average.
NUMBER OF BACTERIAL COLONIES DEVELOPING IN 4 DAYS ON SYNTHETIC AGAR				
Alfalfa	8,308,000	6,600,000	4,500,000	6,469,000
Oats	6,392,000	5,492,000	4,349,000	5,411,000
Corn	5,833,000	5,666,000	3,608,000	5,035,000
Potatoes	5,900,000	6,083,000	4,792,000	5,591,000
Fallow	4,883,000	4,475,000	2,550,000	3,969,000
MILLIGRAMS OF AMMONIA PRODUCED IN 100 GM. OF SOIL IN 4 DAYS				
Alfalfa	50.9	50.7	40.1	47.2
Oats	51.7	57.8	48.1	52.5
Corn	52.8	58.4	45.2	52.1
Potatoes	55.2	64.2	47.9	55.7
Fallow	63.9	73.0	51.2	62.7
MILLIGRAMS OF NITRIC NITROGEN PRODUCED IN 100 GM. OF SOIL IN 21 DAYS				
Alfalfa	3.15	7.48	3.08	4.56
Oats	2.40	4.00	3.00	3.13
Corn	2.18	3.50	1.48	2.38
Potatoes	3.00	15.55	5.60	8.04
Fallow	1.30	5.50	2.48	3.09

The most marked characteristic of all these results is that they are extremely low when compared with the results obtained on other soils, thus showing that the limiting factor is organic matter. The number of organisms is highest in the alfalfa and lowest in the fallow; and, with the

single exception of potato plots in the summer, this same statement holds for the nitrifying powers of the soil. These results would appear to be absolutely contrary to the findings of Heinze (24), Russell (48), and others (5, 47), who have found fallow to increase not only the number but all the bacterial activities of the soil. But it must be remembered that these investigators were working with soil which was alternately fallowed and cropped, and on this there would be left plant residues, while we have been working with a soil which has been continually fallow for 12 years, the organic matter of which has been reduced to a minimum. The results do, however, show the contentions of Hiltner to be unfounded, for the low nitrate content of alfalfa is due to the plant's rapidly removing the nitrates as formed and not due to the lack of nitrifying powers in the alfalfa soil.

COMPARISON OF BACTERIAL ACTIVITIES AND CROP PRODUCED ON SOIL

It is interesting to compare the nitric nitrogen found in the soil and the nitrogen removed in the crop with the various bacterial activities. In order to make these results more comparable, the average nitric nitrogen and nitrous nitrogen in the soil, the nitrogen removed in the crop, the number of organisms developing on synthetic media, the ammonia and nitric nitrogen produced in the laboratory by the fallow soil and the unirrigated soil have been taken as 100 per cent, and each of the cropped and irrigated soils compared with these. The summarized results are given in Table XXXIV.

TABLE XXXIV.—*Comparison of bacterial activities and crop produced on soil*

Crop or treatment.	Nitric nitrogen in soil.	Nitrous nitrogen in soil.	Bacterial colonies.	Ammonifying powers.	Nitrifying powers.	Nitrogen in crop.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Fallow	100	100	100	100	100	....
Alfalfa	36	233	163	76	148	....
Oats	36	167	136	85	103	....
Corn	33	56	127	84	77	....
Potatoes	99	122	141	90	261	....
No water	100	100	100	100	100	100
15 inches	48	115	99	103	98	140
25 inches	51	62	95	96.6	98	140
37.5 inches	43	115	93	104	98	145

These data show that the crop has reduced the quantity of nitric nitrogen of the soil, but has increased the efficiency of the nitrifying bacteria, owing to the removal of the nitrate producer, while, on the contrary, oats and alfalfa have increased the nitrous-nitrogen content. That this is due to the compact nature of the soil is seen from the results, for the nitrous nitrogen increases as the aeration of the soil decreases and is very pronounced in the alfalfa. In the potato soil, which is cultivated, it is less than

in the fallow, which is not cultivated. The crop in every case increases the number of organisms, and this in direct relation to the plant residues left on the soil. However, we find the ammonifying powers varying in the opposite order. The nitrifying powers are increased by the alfalfa and potatoes. Hence, we can conclude that the alfalfa not only feeds closer upon the soluble nitrates of the soil but also makes a much greater drain upon the insoluble nitrogen of the soil by increasing its nitrifying powers. It therefore would deplete the soil if the entire crop be removed, more readily than would any of the other crops.

The application of water has decreased the nitric nitrogen found in the 6 feet of surface soil, but has slightly increased the nitrous nitrogen of the soil, while the number of organisms remain about the same in all the soil except those receiving 37.5 inches of water, and in these the number decreases. The ammonifying powers of the soil are slightly increased by the water, while the nitrifying powers are very uniform. But this holds only for the fall, for during the spring we obtain the following results for nitrifying powers:

	Per cent.
No water	100
15 inches of water	125
25 inches of water	115
37.5 inches of water	135

The nitrogen removed in the crop increases, but not in the same proportion as does the ammonifying and nitrifying powers. Furthermore, we have a rapid decrease in the nitric nitrogen of the soil. Especially is this true where the larger quantities of water are applied. The results therefore indicate that the effect of the excessive use of irrigation is not only a waste but the yield of the crop is depressed, and the depressed yield is due to the water carrying the soluble nitrates beyond the sphere of action of the plant roots. Furthermore, it increases the ammonifying and nitrifying powers of the soil during the spring and summer, with the result that a greater quantity of soluble plant food produced is carried out by the drain waters, and the soil is to this extent needlessly depleted of its nitrogen.

SUMMARY

The quantity of nitric nitrogen in the surface 6 feet of alfalfa soil is comparatively low throughout the season, but is higher in the fall than in the spring or summer. The quantity present decreases as the water applied increases; yet the quantity formed in the soil increases as the water applied increases, but is greatest per acre-inch of water when only 15 inches of water are applied.

The quantity of nitric nitrogen in the surface 6 feet of potato, oats, corn, and fallow soil decreases as the water applied increases; but the quantity formed for each of the cropped soils is greatest where the largest quantity of water was applied. The quantity formed per acre-inch of water applied is greatest where only 15 inches of water were applied.

Large quantities of nitric nitrogen disappeared from the fallow soil during the summer months. This is attributed to the growth of bacteria, which transforms it into protein substances and not to denitrification.

The larger applications of irrigation, 37.5 and 25 inches of water, carry much of the nitric nitrogen beyond the sphere of action of the plant, and this accounts for the decrease in crop yield, which is often noted when excessive quantities of irrigation waters are applied to a soil.

The application of water to a soil depresses the number of organisms which will develop upon synthetic agar in alfalfa, oats, and potato soil, but increases them in fallow. The results obtained with the corn are irregular.

The ammonifying powers of all the soil, except the alfalfa, was increased by the application of irrigation water.

Water increased the nitrifying powers of all the soils except the oat soil.

There was a difference of 2 degrees Fahrenheit in the temperature of the soil of irrigated and unirrigated in favor of the unirrigated. This difference in temperature was perceptible to a depth of 4 feet.

The number of organisms was higher in the cropped than in the fallow plots, and this is probably due to the plant residues left upon the cropped soil.

Naming the soils in the order of increasing ammonifying powers, we have alfalfa, oats, corn, potato, and fallow. By naming them in the order of increasing nitrifying powers, they are fallow, corn, oats, alfalfa, and potato.

The alfalfa not only feeds closer upon the nitric nitrogen of the soil than do other crops but it also increases the nitrifying powers of the soil. Hence, it would deplete the soil of its nitrogen more rapidly where the entire crop is removed than would other crops.

The use of irrigation water increases the bacterial activities of the soil, which render soluble the nitrogen, and where excessive quantities of water are used considerable of this is washed from the soil, thus unnecessarily depleting the soil of its nitrogen. This in turn gives diminished yields on the soil.

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